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REPORT OF THE DEFENSE SCIENCE BOARD

February 1967

Report of the Task Group on Independent Research and Development



Office of the Under Secretary of Defense
for Acquisition, Technology, and Logistics
Washington, D.C. 20301-3140

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Date: MAR 08 2011

Supplement 1

INDEPENDENT RESEARCH and DEVELOPMENT

Report of the
Defense Science Board Task Group

1 FEBRUARY 1967



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INDEPENDENT RESEARCH AND DEVELOPMENT

Report of the
Defense Science Board Task Group
on Independent Research and Development

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Office of the Director of Defense Research and Engineering
Washington, D.C. 20301

1 February 1967

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WASHINGTON, D. C. 20301

Page determined to be Unclassified
Reviewed Chief. RDD, WHS
IAW EO 13526, Section 3.5
Date: MAR 08 2011

4 November 1966

Dear Mr. . . .

The Director of Defense Research and Engineering, Dr. Foster, has requested the Defense Science Board (DSB) to undertake a study of the technical management aspects of Independent Research and Development (IR&D). A number of specific areas for study have been established. One of these is to "Develop meaningful lists of examples of the output of defense contractors' IR&D efforts that are beneficial to the DoD and suggest a simple means of keeping such a list current." In order to respond to this phase of the study, the DSB Task Group established to make this study identified a number of companies with active IR&D programs who would most likely be willing and able to quickly respond to a request for assistance in this area. Your company was one of those chosen.

Assuming that you are agreeable, we would like to have your company submit four or five, more if you so desire, outstanding examples from your past 3 years' IR&D effort that have resulted in significant benefits or payoff to the Department of Defense. The explanation of the benefits is most important and should include such things as time savings, money savings, technological advancement, etc. In order to simplify the response and to make the information easier to use, there is attached a one-page format for your guidance in submitting this information.

Since the Task Group has a relatively short response date for this study, it would be appreciate if your data could be received by November 28, 1966. It should be sent to the Office of the Director of Defense Research and Engineering, Attention: Mr. E. B. Harwood, Room 3D 1028, The Pentagon, Washington, D.C. 20301.

Sincerely,

Thomas L. Phillips /s/
Task Group Chairman

Attachment

EXAMPLES OF IR&D OF DIRECT BENEFIT TO DOD

Title:

Brief Description: (When started, IR&D brochure identification if any, dollars associated with effort—total and government portion of total, significance of effort, etc.)

Benefits to the DoD Resulting from the Effort: (Dollar savings, time savings, technology advancement, resulting equipment, etc.)

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THE **BOEING** COMPANY

HEADQUARTERS OFFICES P.O. BOX 3707 • SEATTLE, WASHINGTON 98124

November 28, 1966

IN REPLY REFER TO

1-8101-717

Mr. E. B. Harwood
Office, Director of Defense Research
and Engineering, OSD
Room 3D1028, The Pentagon
Washington, D. C. 20301

Dear Mr. Harwood:

Mr. T. L. Phillips, Chairman of the DSB Task Group on IR&D, in a letter to Mr. W. M. Allen of November 4, 1966, requested that The Boeing Company submit to you several examples of results of our past three years' IR&D efforts that have resulted in significant benefits to the DOD. These are reported in the attachments to this letter on the format supplied by Mr. Phillips.

Mr. Allen has asked me to reply for him. I believe that several additional comments of a general nature should be made that supplement the specific examples given in the attachments.

The IR&D programs of The Boeing Company are planned first to establish a basis for improvement of existing products such as the B-52, Minuteman, Saturn, Lunar Orbiter, the C-46/47 helicopters, and our commercial airplane products.

Secondly, the programs are directed toward developing the technologies and conducting preliminary systems studies that will be required for us to bid for new systems, such as the TFX, C5A, the AGM-69, and the Supersonic Transport.

Both of the above types of activities lead to proposals to our customers, either for improved products or for new systems. In some cases these are unsolicited proposals. In others, they are submitted in response to requests for proposals. In both cases the government, in these proposals, obtains the benefits of our IR&D programs either through incorporation of the results in contracted programs or through trade studies. Our preliminary systems designs and those of others in industry help establish a basis for analysis of possible options open to the government and are used extensively in preparation of work statements in formal competitions. The IR&D programs conducted by Boeing all contributed substantially in the formulation of the requirements and system definition in the TFX, the C5A, MOL, and the AGM-69 as well as to definition of improved versions of our existing products.

It is my opinion that the government, through both the solicited and unsolicited proposals that they receive, are informed on, and benefit from, almost all of the spectrum of IR&D activities of industry. In addition, technical personnel in government laboratories are in continuous communication with their technical counterparts in industry. They are kept informed, either through the IR&D programs and reports submitted annually to the government or by personal contact.

Since the major contributions to DOD from IR&D activities are in the improved systems resulting from synthesis of a number of technology and state-of-the-art activities, we have attempted in the attachment to emphasize specific systems benefits which resulted from a number of technical activities, as well as several examples which can be identified with improvements in one specific technology.

In the examples, estimated amounts of total applicable IR&D expenditures are given. These can only be considered estimates since many of the technology research activities of the company are germane to more than one system or study. The portion of the IR&D expenditure allowable as an overhead charge has not been identified for each specific example. Allowability of IR&D costs have been negotiated in the past on a corporate basis and not on a project basis.

The examples given in the attachments are in general identified, in accordance with Mr. Phillips' request, with results obtained since 1963. The benefits of most of the IR&D effort conducted during the period 1963-1966 are yet to be realized, but many results of the effort have been communicated to DOD and are being considered and evaluated by groups within the DOD.

We hope this information will be of use to you. If you wish any additional information on data on this subject, please don't hesitate to call me directly.



B. F. Ruffner
Director - Product Research

Attachments

EXAMPLES OF IR&D OF DIRECT BENEFIT TO DOD

TITLE: AGM 69A -- Air-to-Surface Missile System

BRIEF DESCRIPTION:

An IR&D program has been in effect for three years with the objective of assisting the DOD in the definition of an effective air-to-surface missile system for the Air Force. This has involved extensive preliminary design and technology research activity. The major technical results that were achieved as a result of the activities were:

1. Development of a technique for in-flight alignment of the navigation systems (Kalman).
2. Development of techniques for the reduction of drag in low-altitude missiles.
3. Development of materials suitable for the high-temperature operating environment.
4. Experimental development of missile shapes that would achieve less probability of detection by enemy radar.

As a result of the work done in this IR&D program, the company was in a position to compete effectively in the AGM-69 competition.

The total IR&D funding is estimated to be about \$390,000. As a result of the industry-wide competition, Boeing was awarded a contract of \$142,300,000 for the development of the system with an additional initial production option of \$93,500,000.

The results of this research as directly applicable to AGM-69A are contained in the following research reports and tests and AGM-69A program documents.

| | |
|-----------------|--|
| T2-3382-1 | Van Guidance Tests |
| D2-34013-1 | Optimum Smoothing Navigation |
| AFMDC-TR-66-106 | Inertial Van Test, Third Inertial Guidance Test Symposium |
| D2AGM12302-19 | Avionics Inertial Update |
| D2AGM12413-1 | Analysis Report, Wind Tunnel Test |
| D2AGM12302-10 | Missile Body - Fin Materials and Construction Trades |
| D2AGM12225-1 | Missile Radar Cross Section |
| D2AGM12302-20 | Radome/Forebody ARH Antenna Trade |
| D2-125121-1 | Process Requirements for Fabrication of Molded Control Fin Assemblies |

BENEFITS TO DOD RESULTING FROM THIS EFFORT

The AGM-69 will, as a result of the IR&D programs, have superior mission performance in several respects. The guidance system will incorporate the techniques discussed above. This will improve the accuracy. The aerodynamics and materials testing gave a technical foundation which will enable the missile to meet its speed, altitude, and weight specifications. The radar return testing enabled the development of a missile configuration that is not only aerodynamically efficient but will also present a small target for detection by enemy radar.

TITLE: Boeing HiBEX IR&D Effort

BRIEF DESCRIPTION:

IR&D research was implemented in 1960 in the area of high-acceleration boosters, to satisfy requirements of an anti-ballistic missile. Specific IR&D effort undertaken included advanced defense techniques, high-acceleration propulsion, fast-response maneuverability and control during boost phase, hot launch of a missile with closed breech, and the survival of electrical and mechanical equipment in a very high-acceleration and high-dynamic-pressure environment. This research lead to a contract, DA-01-021-AMC-10696(2), under the direction of ARPA.

Program effort required approximately \$450,000 in Boeing IR&D funds. The HiBEX contract value was \$22,000,000.

Significant IR&D documentation includes: D2-35005, Hardsite/Urban Defense Missile Six Week Study Report; D2-35007, Sprint Technical Task Description; D2-22294, Plasma Research - Hard Point Missile; D2-35010, Preliminary Description - Combo Terminal AICEM Interceptor; D2-20864, Hard Point AICEM Studies - Supplementary Technical Data; D2-22676, HiBEX Design Data; D2-22557, High-g Boost Experiment Oral Presentation; D2-20228, Hard Point Defense Interceptor (HPDI) Experiment; D2-22472, High-g Boost Experiment Technical and Management Proposal.

BENEFITS TO THE DOD RESULTING FROM THE EFFORT

The HiBEX program and associated research have provided a significant increase in the demonstrated high acceleration booster technology and have validated the feasibility of very high-acceleration intercepts. Further, it has been demonstrated that a system with fast reaction time can be developed with low-altitude commitment which greatly simplifies radar requirements. The results of this have not yet been incorporated in a defense system, but the technology developed should form a significant building block for future systems.

TITLE: Boeing Upper Atmosphere Clear-Air-Turbulence Detection (CAT) IR&D Effort

BRIEF DESCRIPTION:

Effort embracing investigation of radar techniques for detecting and locating clear-air turbulence (CAT) was initiated in October 1963, with a successful bistatic VHF radar experiment to correlate radar echoes with CAT and wind-shear.⁽¹⁾ Later a pulsed 220-MHz radar was put in operation to observe CAT layers at vertical incidence.⁽²⁾ During the winter 1965-66 a VHF radar was operated on a Boeing 727 against CAT. During 60 flight hours there were twelve encounters with CAT. Each time, CAT radar echoes were observed in the "window" inside the radar altitude circle.

IR&D costs are at a rate of approximately \$240,000 per year.

Publications:

1. "A Note on VHF Backscatter from Turbulence in the Upper Troposphere," Jour. Appl. Met., 4 February 1965.
2. "Radar Detection of Turbulence in the Upper Troposphere," paper presented at the National Air Meeting on CAT sponsored by ION/SAE Washington, D. C., 23-24 February 1966.

BENEFITS TO THE DOD RESULTING FROM THE EFFORT

This work represents a significant step forward in the development of an airborne CAT detector. It has been established that stable layers, windshear and CAT, itself, produce detectable echoes on both ground (vertical incidence) and airborne (horizontal incidence) radars. Present work is focussed on optimum detection wavelength and on the best antenna-beam-pointing geometry. Hopefully, an operational on-board CAT detector will be developed that can complement present weather (raindrop) radars used on MAC transports and heavy bombardment aircraft. Use of such a detector could be instrumental in avoiding loads that could cause structural overload or fatigue failure.

TITLE: Boeing Helicopter Performance Improvement

BRIEF DESCRIPTION:

Beginning in 1963, a continuing program has been under way to design or select airfoils that would produce significant gains in helicopter-rotor performance capabilities. A number of airfoils embodying changes to the leading-edge radius and the amount of camber were designed and tested. Results showed that the use of thin airfoil sections having reduced camber and a moderately blunted nose provided a superior combination of lift and drag characteristics. These led to the development of a new cambered airfoil section referred to as a "droop-snoot" section. Design features included replacement of the nose cap and use of the existing spar with a 6-inch tip extension and honeycomb-filled trailing-edge boxes. Flight tests of prototype "droop-snoot" blades were run in 1964 on a CH-46A and confirmed predicted improved performance, vibration, stability, and rotor limit characteristics. Similar CH-47 droop snoot tests were flown in 1966. As a result of the large performance gains demonstrated by the Boeing-Vertol droop-snoot blades, contracts were negotiated to incorporate these advances in both the CH-46 and the CH-47 programs.

The CH-46D completed qualification trials in 1966 with the following change in performance (which result in a 50-percent increase in productivity):

- a. 40 knots' maximum speed increase (from 115 to 155 knots).
- b. 1000 pounds' payload capability increase (from 4230 to 5288 pounds at 6500 feet, standard day).

Deliveries on the CH-47B will begin in 1967 with the following improvements (which result in a 58-percent increase in productivity):

- a. 45 knots' increase in maximum speed (110 to 155 knots).
- b. 1100 pounds' increase in payload (from 5492 to 6592 pounds at 6000 feet, 95°F).

Funds expended in the development:

| | | |
|-------------|---|-----------|
| Boeing IR&D | - | \$720,569 |
| Government | - | \$ 77,000 |

BENEFITS TO THE DOD RESULTING FROM THE EFFORT

The results of the effort provide a significant improvement in vehicle effectiveness in the missions of the Army and the Marines, who are now using earlier models of these helicopters in Vietnam.

TITLE: Boeing Helicopter Flying-Quality Improvement IR&D Effort

BRIEF DESCRIPTION:

Improvement of flying qualities for both the CH-46 and the CH-47 aircraft has been a continuing IR&D effort since 1963 in the following areas:

1. Stability-Augmentation System (SAS)

In 1963, Boeing-Vertol completed design and development of the Mark II SAS. This new SAS differs from the old in that it uses mechanical feed-back actuators, is not dependent on the aircraft AC power supply, its circuitry is improved, and its electronics is greatly simplified. By mid-1964, a breadboard version was constructed. In 1965 further development was directed toward refinement testing, modification of circuitry, working on inverter problems, finalizing transducer design and incorporation of results into the CH-46 and CH-47 aircraft systems.

2. Automatic Stabilization System (ASE)

Conventional altitude-hold systems depend on atmospheric pressure sensing, but are not suitable for the helicopter when in ground effect. Radar altimeters have been used, but are costly and not very reliable and produce a noisy output. The ASE developed in 1963 uses a combination of pressure and inertial sensing; hence, it is considerably less expensive than a radar altimeter. The ASE has been developed for use on both the CH-46 and the CH-47 aircraft.

3. CH-46 Aft-Pylon Drag Reduction

Prototype hardware for the aft-pylon trailing edge was designed and developed during 1964. Drag-reduction results led to a proposal to the Navy to install ramp fences and a trailing-edge fairing.

4. CH-46 External-Noise-Level Reduction

Flight tests completed in 1965 indicated that rotor tip-path plane separation can reduce noise.

5. CH-47B Pylon Improvements

In 1964 a study was initiated to determine proper height of the aft pylon to provide optimum vertical separation of the forward and aft rotor blades in order to reduce rotor noise and rotor stress spikes in the outer section of the rotor blades. In addition, a program was initiated to study directional stability relevant to the forward pylon.

6. CH-47B Vibration Reduction

Under a continuing vibration-reduction-analyses program, four systems were developed: cockpit and cabin absorbers, force balancers, blade-root pendulums and swashplate damping.

Funds Expended

| | | |
|------------|---|-----------|
| Boeing | - | \$359,574 |
| Government | | \$156,000 |

BENEFITS TO THE DOD RESULTING FROM THE EFFORT

The contribution of the Mark II SAS on the CH-46 and CH-47 aircraft as an advancement to the state of the art has resulted in greatly increased producibility, reduced maintenance, increased reliability and substantial improvement in operational characteristics. Because of its simplicity and greater reliability as compared to a radar altimeter, the ASE has also been a major contributor to the state of the art. In addition, it has the capability to hold altitude when hovering near large objects such as aircraft carriers which give spurious reflections.

With forward pylon fairing removed and aft pylon extended, neutral yaw stability was achieved for the CH-46D. Also, varying cyclic trim schedules in conjunction with hovering of the forward hub for blade separation contributed to alleviation of the rotor "bang" noise problem.

Spoilers, strakes and a blunted aft pylon have rendered the CH-47B neutrally stable directionally.

As a result of vibration absorber IR&D, the CH-47B has demonstrated considerable vibration improvement throughout the entire speed range. A substantial reduction has been shown with both cockpit and cabin absorbers.

The resulting improvements in vibration and stability have allowed the CH-46D and CH-47B/C to take advantage of the 40-knot performance advantage offered by the droop-snoot blade.

TITLE: Investigations of Armor for Helicopters and Crash Safety.

BRIEF DESCRIPTION:

Since 1964 advanced types of lightweight armor have been evaluated. A test program evaluated the effects of ballistic damage on the integrity of helicopter components and crew protection. A proposal to the Army was submitted and a contract award was made.

Boeing IR&D funds - \$214,000

Government contract - \$442,000

BENEFITS TO THE DOD RESULTING FROM THE EFFORT

The above effort resulted in establishing the armor configuration and the armored crash-safe crew seat for the armed Chinook. Four Chinook (CH-47) helicopters incorporating these improvements were delivered four months from date of contract. They are currently undergoing service evaluations.

TITLE: Boeing IR&D Meteor-Burst Communications Effort

BRIEF DESCRIPTION:

Beginning in 1960, an extensive analysis and testing program was undertaken in the area of meteor-burst communications (utilizing reflections from meteor trails). As a result, there was provided extensive experience in the design of equipment for operation of this type of communications link, which is not only secure but is more survivable than other over-the-horizon communications.

Significant applicable IR&D documentation is D2-125126-1, "Secure and Survivable Communications"; and D2-20788, "Meteor Scatter Burst Communications Research Program."

This program has required approximately \$300,000 in Boeing funds and \$500,000 of government funds up to this time. The government funds were a direct contract and not overhead funding of the Boeing IR&D program.

BENEFITS TO THE DOD RESULTING FROM THE EFFORT

As a direct consequence of this activity, a complete experimental meteor-burst communications system was built offering unique operational advantages, and is being used operationally, as well as for system test and evaluation, by the government.

TITLE: Fracture Mechanics

BRIEF DESCRIPTION:

Fracture mechanics is the science of stressed bodies containing cracklike defects, and includes as a major facet the formulation of stress intensity solutions for various flaw geometries, orientations, and external loading conditions. In addition, this technology covers the development of mathematical models for sustained load flaw growth and for cyclic loading flaw growth.

Our fracture mechanics research has provided a powerful tool that has made possible a major advance in our ability to obtain solutions for service failures, to provide life-prediction techniques for preventing future failures and for establishing inspection and test standards of metallic parts and components.

Our research in fracture mechanics during the past three years was as follows:

| | <u>BOEING IR&D</u> | <u>USAF CONTRACT</u> | <u>NASA CONTRACT</u> |
|------|------------------------|----------------------|----------------------|
| 1964 | \$44,000 | \$695,000 | \$335,000 |
| 1965 | 49,000 | --- | 381,300 |
| 1966 | 15,000 | --- | 279,000 |

Applicable documentations include:

C. F. Tiffany and F. A. Pall, "An Approach to the Prediction of Pressure Vessel Minimum Fatigue Life Based upon Applied Fracture Mechanics," Boeing Document D2-22437, March 1963.

ASTM STP 381, "Fracture Toughness Testing and Its Applications," June 1964, p 249.

C. F. Tiffany, P. M. Lorenz, "An Investigation of Low Cycle Fatigue Failures Using Applied Fracture Mechanics," ML-TDR-64-53, May 1964.

C. F. Tiffany, P. M. Lorenz, L. R. Hall, "Investigation of Plane Strain Flaw Growth in Thick Walled Tanks," NASA CR-54837, February 1966.

A. S. Kobayashi, "On the Magnification Factors of Deep Surface Flaws," Boeing Structural Development Research Memorandum, SDRM No. 16, December 1965.

BENEFITS TO THE DOD RESULTING FROM THE EFFORT

Analytical solutions and techniques have been developed for a number of different commonly encountered types of flaws and defects and flaw-growth mechanisms. We have developed quantitative data on the effects of flaws

under sustained loads and cyclic loads. We are able to predict the life of parts and the failure mode. Furthermore, this technology provides a high degree of confidence for selecting the best material for the design loading and service environment. In addition, it will provide the basis for improved standards in proof testing and nondestructive testing (NDT) inspection.

It is difficult to make an accurate assessment of the time and dollars that will be saved as a result of the fracture mechanics technology's impact on material selection, design, manufacturing processing, life prediction, reliability, proof-test requirements and inspection requirements. One thing is certain--and that is, the savings will be large.

TITLE: IR&D Leading to Lunar Orbiter Program

BRIEF DESCRIPTION:

In November 1963, technical studies of the feasibility of, and requirements for, large-area, high-resolution photographs of the moon were instituted. These were focussed on:

1. Development of technical arguments validating the need of large-area, high-resolution photography of the moon to ensure identification and location of Apollo landing sites.
2. Detailed technical studies of the photographic subsystems necessary to execute the photography of (1) above.
3. Preliminary design of several alternate spacecraft configurations suitable for the Lunar Orbiter missions but sized, weightwise, to several possible launch vehicles' capabilities.
4. Detailed analyses of communications, guidance, attitude control, power, and thermal subsystem designs for an Atlas/Agena-sized Lunar Orbiter.

In August of 1963 a request for proposal was received, and a proposal was submitted in October 1963. A contract to Boeing was obtained December 20, 1963. The effort prior to contract award, including the proposal preparation, was not supported by government contract. Approximately \$693,000 of IR&D funds were used prior to the contract period.

This is a typical example of the work performed under IR&D funds.

BENEFITS TO GOVERNMENT RESULTING FROM THE EFFORT

Thus far, two orbiters have been launched and have performed in an outstanding fashion. High-resolution photographs have been obtained, with a resolution of less than 3 feet. The photographs will aid substantially in identifying areas of the moon on which a vehicle can land safely with a man aboard.

TITLE: Boeing Titanium Technology Program

BRIEF DESCRIPTION:

A comprehensive program initiated in mid-1963 to provide a sound base for the airframe structural use of titanium alloys. Undertaken primarily to support the Company-sponsored SST design studies, it includes design, development, fabrication and testing of representative airframe components.

For the two and one-half years from mid-1963 to the end of 1965, Company funding totaled approximately \$6.5 million, exclusive of capital facilities. The current (1966) annual expenditure rate is approximately at the \$2-million-per-year level. The findings of this program are made known through the normal distribution channels for contractor IR&D reporting and in the annual Contractor IR&D Reports.

BENEFITS TO THE DOD RESULTING FROM THE EFFORT:

Major benefits, applicable and being applied to current AMSA (advanced manned strategic aircraft), US/FRG (United States/Federal Republic of Germany), and tactical aircraft studies include:

1. Identification, in early 1965, of Ti 6-4 alloy as unsuitable for many airframe applications because of its susceptibility to early stress corrosion cracking and failure. This was followed by the confirmation of Ti 6-4 alloy as the currently most suitable alloy for airframe structures.
2. The development and demonstration of practical methods of machining, forming, extruding, casting, forging and fastening/joining processes required for the fabrication and assembly of aircraft structures.
3. The development of a titanium design technology soundly based upon both the unique properties of titanium and the manufacturing processes.

TITLE: Minuteman System Improvements

BRIEF DESCRIPTION:

Major recent efforts conducted under the IR&D program have been focused on the following areas:

1. Improvement in the launch-control system permitting greater command and control flexibility.
2. System design studies of an airborne launch control center and airborne command post.
3. Proposal to modify Vandenberg Air Force Base for compatibility with Minuteman II missiles.
4. Design studies of means of incorporating launch-status authentication in improved launch-control system.
5. Permissive link studies.

The above work culminated in the proposal of a replacement of the existing Minuteman system that provided the following capabilities: squadron-wide status reporting, communication link between the airborne launch-control center and command post with the Minuteman system, improved survivability of Wings I and II, compatibility of the launch-control system of early Minuteman Wings with the later designs and increased targeting capability per missile.

Significant IR&D documentation is as follows:

| | |
|------------|--|
| D2-15739-2 | WS 133A Launch Control System Improvements for Control of LCM 30F Missiles Simplex Concept |
| D2-15739-1 | WS 133A Force Modernization Program Preliminary |
| D2-20145-1 | Survivable Missile Away Signal Transmission and GMT Recording |
| D2-20162-1 | Improved WS 133A Launch Control System Technical Proposal |
| D2-20162-2 | New and Modified Fig. A's Improved WS 133A Launch Control System |
| D2-20182-1 | WS 133A/LCM 30F Compatibility Launch Program VAFB Proposal #1 Standard WS 133A LCS |

| | |
|---------------|--|
| D2-20182-2 | WS 133A/LGM 30F Compatibility Launch Program VAFB Proposal #2 Improved LCS I |
| D2-20182-3 | WS 133A/LGM 30F Compatibility Launch Program VAFB Proposal #3 |
| 2-7843-31-039 | WS 133A LCS Modified To Provide Command and Control of LGM 30B and LGM 30F Missiles in Mixed Complement |
| D2-11606 | Airborne Launch Control System |
| D2-12596 | Ground System Specification for Minuteman II Configuration Employing RICS |
| D2-35063 | Minuteman Launch Control System Improvement Study Wings I - V |
| D2-35106 | Minuteman Launch Control System Improvement Study (MF Radio Status) |
| D2-35152 | Permissive Link System for Minuteman |

The program required approximately \$700,000 of IR&D funds.

BENEFITS TO DOD RESULTING FROM THIS RESEARCH

Based on the above data, a Program Change Package was initiated which called for the following requirements to be implemented:

1. Squadron-Wide Status Reporting
2. Time-on-Target Control
3. Radio Launch Overlay
4. Multiple Execution
5. Launch Enable Execute Subsystem
6. Utilization of LGM-30F Missile
7. Missile Away Time Prediction
8. Extended Survivability Wing I and II

This research lead to a timely and cost effective modernization of the Minuteman system.

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Lockheed
MISSILES
& SPACE
COMPANY

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IAW EO 13526, Section 3.5
Date: MAR 08 2011

November 22, 1966

Mr. Elliott B. Harwood
Task Group Executive
Office of Assistant Director
(Engineering Management)
ODDR&E, Rm 3 D 1028 Pentagon
Washington, D. C. 20301

Dear Mr. Harwood:

Enclosed is a copy of material prepared at LMSC last summer in connection with a study we were making on the uses of past IR&D work. I am submitting it as LMSC's response to the DSB Task Force request for examples of useful IR&D.

* * *

Sincerely yours,

Wayland C. Griffith

Wayland C. Griffith
Vice President
Research and Technology

Encl.

A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION
SUNNYVALE, CALIFORNIA

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8/2/66

MISSILES & REENTRY VEHICLES

Independent Research (IR) funds are used at Lockheed Missiles & Space Company to assist in the investigation of fundamental problems in areas which are now, or are expected to be, of importance to defense problems and national scientific goals. The funds enable us to pursue programs which will attract and maintain scientists capable of making original contributions in their respective disciplines carrying them to the point of engineering application. By divorcing these individuals from immediate design responsibilities, project functions and deadlines, their ability to keep abreast of rapidly changing developments is maintained and their continued contact with the scientific society is ensured.

The research findings are fed directly to the LMSC project organizations and government agencies by means of informal consultations, memoranda, symposia, colloquia, etc. The final output of research programs always appears in the open literature as publications or Lockheed reports receiving wide distribution.

The Independent Research program at Lockheed Missiles & Space Company was formally instituted as a separate reporting activity in 1956. Coincidentally several major national programs were initiated at about the same time, give or take a year. These included Titan, Polaris and WS-117-L, the satellite program. At about the same time the first serious attempts by contractors to design missile defense systems were begun, and the Atlas missile program, which had been in existence for several years, was apparently rejuvenated. Shortly thereafter, the Minuteman program came into being. Let us, with a ten-year backdrop of experience, review the problems which existed at the time and the solutions which were applied to these problems and examine the contributions of LMSC's independent research efforts to the solutions of some of these problems. While this discussion may use largely examples of the Polaris missile system, similar problems were faced by other programs, and the research efforts quoted here were useful to those programs.

Reentry Problems

In 1956, the first year of independent research at LMSC, the major problem in the reentry-body area was how much aerodynamic heating would be incurred and what to do about it. The Allan & Eggers solution for reentry heating, which showed that total heat load varied with the parameter β , was available, and several approaches to estimating convective heat transfer coefficients had been started. The problem, still, was how to cope with the reentry environment. The problem of heat transfer and heat protection was paramount: although the general principles of convection

were understood, measurements of certain parameters were required for quantitative values to be obtained; basic principal properties of air were poorly understood. Fluid mechanics problems such as the stability of boundary layer flows and criteria for turbulent transitions were only begun. The influence of thermal radiation on heat transfer was poorly understood: the radiative properties of air at elevated temperatures were only qualitatively understood. One suspected that new chemical species would be formed and that these would effect radiant heating, but experimental measurements were required to determine reaction rates and atomic radiation constants before estimates of emissivities could be made. What to do with this heat, the problem of heat protection, was another major problem. It could be absorbed by a temperature increase of the material, if a material could be found with the proper values of thermal conductivity and high-temperature strength to avoid extreme thermal stresses and with such a thermal capacity that it could absorb the reentry heat without excessive weight requirements. Another approach recognized was the possibility of absorbing heat by endothermic phase changes such as sublimation or by endothermic chemical reactions--pyrolysis--or by combinations of these. Again, there were problems of suitable materials: sufficiently low thermal conductivities that the reactions are not occurring throughout a large region of the material are required, and a sufficiently high heat-absorbing capability that excessive weights were avoided. A third approach was the consideration of injecting a coolant through the vehicle skin into the boundary layer: transpiration cooling. Here there were problems of injection control, to assure proper distribution of coolant, of coolant heat capacity, etc. All of these approaches required materials and structures with sufficient strength at the temperatures involved to withstand the reentry loads and with surfaces that would resist chemical and mechanical erosion by high temperature.

The determination of the reentry loads, too, was not well developed. Although supersonic ($1 < M < 5$) aerodynamics was a fairly well established art, the extension of this low-temperature technology to the hypersonic region where the air properties may rapidly vary with temperature was recognized as dangerous. There were, as a result, many uncertainties in aerodynamic predictions of loads and of vehicle stability which required experimental measurement to determine the needed factor.

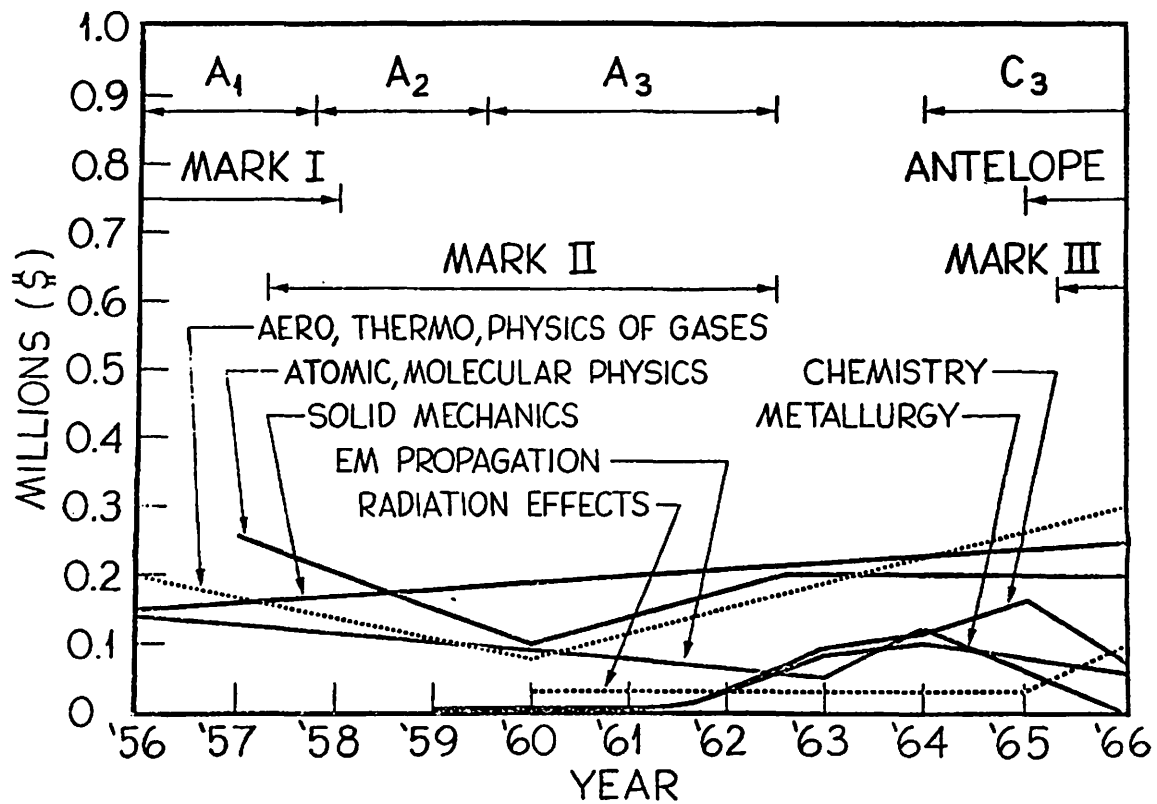
Missile Problems

In missiles, similar problems were faced, and more. These included problems of heating, propulsion efficiency, weight, strength and accuracy. An azimuthal error of one degree at burnout, assuming all other factors perfectly known, results in nearly 100 miles' error in impact point on an ICBM trajectory, the error being approximately linear with range. Velocity and elevation errors contribute just as significantly to impact error. Thus, precise control is required to achieve any usable impact accuracy. Accurate guidance and control concepts and systems were needed. It was recognized that a ballistic-missile war would require land-based missiles to be launched in an extremely short time, and that radio-command guidance offered too many problems of interference. Hence, inertial guidance was an obvious choice. Submarine-launched missiles require self-contained guidance because of the limitations of their operating environment. As a result, there were requirements for very accurate, lightweight gyros and computers for on-board use and few, if any, suitable methods for providing them.

The short reaction times required, together with the hazards associated with the then--and, to a certain extent, now--available storable liquid propellants led to the conclusion that solid rockets were desirable, but the solid motors then available had problems of low specific impulse, heavy motor case and nozzle weight, and essentially no suitable method for thrust vectoring which is mandatory for precise control. Solutions were needed which would lead to higher specific impulses and lighter motor cases--hence, to lower weights, to heat-resisting lightweight nozzles and to suitable methods for thrust-vectoring solid rockets.

This recitation of technical problem areas is almost a summary of the 1956 Lockheed Independent Research Report. Had we included a discussion of ABM, discussed later, we would have an almost complete summary. As the desirability of the solutions indicated by certain of these early programs was recognized, the efforts became funded by research contracts or by major programs, and Independent Research turned to the investigation of even more desirable approaches, but with a diminishing emphasis as the several areas of technology were reduced to practical engineering application. Some of the efforts were more and more directed toward refinements--improved methods which would result in higher reentry speeds, greater accuracy and lessened weight for reentry vehicles, and to larger payloads, lower gross launch weights and improved accuracy for missiles. This trend is seen in the succeeding Independent Research reports.

IR EXPENDITURES



Missile Defense

At about the time of increased emphasis on strategic missiles, the first attempts were undertaken to design missile defense systems. Here the problem areas were even more extensive. In addition to the missile problems reviewed above, all of which pertain to either the interceptor or the target, there were vast areas of ignorance in acquisition, tracking, identification, kill mechanisms and the effects of one intercept on another. The major obstacles were in techniques for identifying warheads in a swarm of decoys and in the areas of weapons effects, both on the target vehicle and on the surrounding environment.

The ABM systems development programs succumbed to the impact of these areas of scientific ignorance, and defensive strategy for several years was based on the dictum that "the best defense is a good offense". Development work continued in the attack-missiles problems until these were solved, and ABM systems development was shelved. However, research into the areas of weapons effects, discrimination, tracking and blackout continued, supported in part by research contracts. As the technology developed, it was recognized by the strategic missile forces that a few--very few--developments could make missile defense a working reality. This realization brought about a concern for hardened strategic systems; first in the reentry vehicles and in penetration systems, later in the launching portions of the missile. This realization came at about the time that fully acceptable missiles for a peaceful environment were working. The major effort now in missiles and reentry vehicles is hardening.

The attached figure depicts the level of funding of several disciplines whose research outputs are of direct significance and benefit to strategic missiles--in particular, Polaris-Poseidon missile systems. Superimposed on the chart is shown the time phasing of the various versions of these two missile systems and their reentry vehicles.

Several interesting facets are worth pointing out. The metallurgy and chemistry programs were initiated in 1959 coincidentally with the selection of an ablator for the Mark II reentry vehicle. These two programs have received continued emphasis in view of the nuclear-effects hardening concerns elicited by the C-3, Antelope and Mark III programs.

Similarly, the radiation-effects program witnessed an upsurge in 1965 in recognition of the impact of radiation damage and its preventive modes on the C-3 and Antelope program.

The interaction of electromagnetic wave with plasmas, labelled EM propagation, has seen a renewed emphasis in 1963 in connection with wake discrimination. Lately this area of research, owing to defense national interest, has been entirely supported by research contract with government agencies and support from MSD organizations.

The atomic- and molecular-physics disciplines indicate an increase in funding level in 1960 coincidentally with serious interest in anti-ballistic-missile defense and the necessity of defining accurately the nuclear-fireball environment.

Finally, the aerodynamics, thermodynamics and physics of fluid effort show at the same time period a funding increase reflecting interest in high-temperature phenomena due to higher reentry speeds, passage through hostile nuclear environments, and wake phenomenology.

Independent Research Outputs

It is difficult and time and space consuming to list the contributions of Lockheed's Independent Research program to technology in terms of the specific technologies. How, for example, does one recognize the somewhat obscure, but direct, relationships between shock-tube research and radiation hazards to man in space, or between measurements of intergalactic distances and the hardening of reentry vehicles to nuclear explosions? In the first case, shock-tube research produced the fundamental atomic constants needed for interpretation of spectra of the aurora borealis. The aurora is one of the effects of solar activity which produce much of the space-radiation hazard to man. Research in auroral mechanisms leads to a considerable insight as to the composition and distribution of near-earth space radiation; one needs atomic constants, which are best measured in shock-tube experiments, for much of the interpretation. In the second case the conversion is more direct. The absolute luminosity of certain types of pulsating stars is a unique function of their period of pulsation. Thus, their distance can be measured by measurements of period and apparent luminosity and applying the inverse square law. However, the absolute luminosity is difficult to measure, even intragalactically, and a calibration is sought using a theoretical model of the star. The mathematical equations which describe the star turn out to be exactly the equations which describe the explosion of a nuclear weapon in the atmosphere. The now famous Hillendahl model for atmospheric nuclear explosions, which is used in all the blast-hardening programs in this country, is really a model of a Cepheid variable star.

Many such cases exist where there is an intimate relationship between seemingly widely separated technologies. Not all of these, of course, involve areas in which Lockheed's Independent Research is contributing, as in the above example, to all facets of a scientific manifold.

It is simpler, at this time, to list the contributions by discipline and time span and to let the interested reader verify these conversions. Therefore, we have chosen the cataloguing sequence for the following listing of Independent Research publications to be one in which a minimum of duplication results.

Aerophysics, Aerothermodynamics and Physics of Fluids

Radiation Effects

Electromagnetic Theory (Radiation, propagation, antennas, breakdown, etc.)

Mathematics and Combustion

Solid Mechanics

Chemistry, including propulsion, corrosion, reactions, etc.

Metals - Metallurgy, ceramics, including physical properties

AEROPHYSICS, AEROTHERMODYNAMICS AND PHYSICS OF FLUIDS

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Page determined to be Unclassified
Reviewed Chief, RDD, WHS
IAW EO 13526, Section 3.5
Date: MAR 08 2011

SATELLITES AND SPACE

New problems were encountered in the development of satellite and space systems. It was necessary for these systems to operate in the space environment for a prolonged period of time. Many features of the environment required clarification. Knowledge of the composition of the upper atmosphere was required to determine the orbital lifetime and the attitude-control requirements of the satellite. Information was needed on the ionospheric structure--in particular, layering and inhomogeneities--for communications applications and for the prevention of electrical breakdown during staging operations. Information was required on the radiation environment in space.

Possibly the most stressing problem was the need to develop a passive thermal-control system which would maintain the temperatures of components to within appropriate limits during the lifetime of a satellite mission. For this design scientists working on IR programs provided information on the solar spectrum, the spectral intensity and spatial distribution of solar radiation reflected from the earth, the characteristics of the terrestrial thermal emission, the albedo of various terrestrial surfaces and clouds, the absorption and emission characteristics of various materials and coatings, and heat-transfer characteristics. In order to avoid deterioration of the thermal system, it was necessary to evaluate the effects of environmental parameters on the surface materials. This analysis required information on the properties of interplanetary dust, resident gases, and solar ultraviolet and x-rays, and on the interaction of these particles and radiations with the surface materials. Moreover, for purposes of reliability it was necessary to build a "space-environment" chamber to test the operation of the complete system. Information for the design of this chamber was provided by personnel who were engaged in IR, and an IR program was directed in support of this work.

Another important space-environment problem was the influence of radiation on satellite components. Many IR programs have been devoted to this problem. Investigations were made of geomagnetically trapped particles, galactic and solar cosmic rays, solar-flare radiations, auroral particles, and nuclear-weapon radiations. These investigations are continuing since this information is becoming of increasing importance now that manned flights are being carried farther into space.

IR support on the problems listed above was given at the time the problems arose. However, because of appreciable delays which generally occur before scientific work is published, the timeliness of the support is not apparent from the dates appearing on related IR reports and publications.

A few publications arising from the support described above are listed here. A complete listing is contained in the IR reports.

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DEEP SUBMERSIBLES PROGRAM

In anticipation of ocean exploration and the development of deep ocean systems as future IMSC lines of business, members of the Lockheed Palo Alto Research Laboratory recognized some of the associated problems, and initiated research projects in related structures and materials. Strength and stability of pressure hulls operating at great depths were of critical importance for the protection of crew and instruments. Accordingly, analytical and numerical investigations were initiated to develop techniques which would permit rapid determination of stresses in externally pressurized shells of revolution with cutouts and variable wall thickness (1,2). Some results of these investigations have been reported in technical journals and widely distributed research reports (3,4,5). In particular, a computer program is in almost daily use in the design of pressure hulls for the Deep Quest and the Deep Submergence Rescue Vehicle. Stability investigations have been continued under the Lockheed Independent Research Program since 1958 (6,7,8,9). Until recently, these studies have been devoted principally to cylindrical shells, dealing with effects of boundary support conditions, reinforcements and geometrical imperfections on the critical buckling pressure for cylindrical shells. Since 1965, emphasis has shifted to the more general problem of stability of externally pressurized shells of revolution. As a result of this study, a computer program is being developed which will predict buckling pressures for single spheres, tandem spheres, and other shapes of practical importance in pressure hull design.

On a related subject, recent research effort has been directed to the study of potential failure mechanisms in buoyancy concepts for deep submersibles. In particular, a study is under way to determine the failure mechanism in the sympathetic collapse of individual glass spheres used for buoyancy (10). It has already been established that the primary hydrodynamic pressure and flow fields associated with single sphere collapse are qualitatively sufficient to produce stresses in excess of the fracture strength of adjacent glass spheres if the standoff distance is not sufficiently great. Calculations are now being carried out to determine quantitatively the stand-off distance necessary to prevent chain failure of adjacent spheres.

In 1960 an Independent Research study of materials for pressure-loaded structures was undertaken to determine the suitability of a sub-size test specimen for evaluating materials for internally pressurized structures (11). From these beginning

considerations of ductility during biaxial loading, I. R. studies then progressed to an evaluation of a reported anisotropy in elastic modulus of 18 U1 maraging steel (12), and an evaluation of fracture toughness in plate thicknesses of 250 and 200 grades maraging steel, applicable to large-diameter rocket boosters (13).

With the knowledge of pressure-loaded structures obtained from these studies, as well as the continued contacts with the current literature, it was possible to estimate comparative weights of very large rocket boosters made respectively of maraging steel and of wound-filament reinforced plastic (14). This knowledge allowed us to predict the capabilities of various material candidates for pressurized applications when the pressure was external, as for submersibles (15).

The accumulated knowledge from I. R. programs, current literature awareness, and supplier contacts enabled the selection of a suitable material for the Deep Quest pressure capsule without resort to an elaborate selection test program. In fact, it was possible to make modifications of a standard composition more closely conforming to the special requirements of notch-toughness desired by BuShips for submersibles without an elaborate and costly test program. The effectiveness of this selection was demonstrated when the Deep Quest pressure capsule passed an 8500-foot-depth test.

It is recognized that generally a time lag may occur between the actual research effort and its subsequent publication. Throughout this program, therefore, a close working relationship was established between scientists and advanced design engineers to permit the incorporation of the latest research results on a current basis. Thus, the final design utilized the most recent advances in knowledge rather than depend upon published information, which often lags behind current developments.

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- (2) "Independent Research Report for 1964," LMSC Report No. 5-13-65-2; p 162, "Shell Analysis," p 167, "Oceanographic Structures."
- (3) "Influence Coefficients of a Circular Cylindrical Shell with Rapidly Varying Parabolic Wall Thickness," D. Bushnell and N. J. Hoff, AIJA J., 2, No. 2, 2167-2173 (Dec. 1964).
- (4) "Analysis of Short Cylindrical Shells of Variable Wall Thickness," O. Hoffman and W. E. Jahsman, AIJA J., 4, (Sep. 1966), LMSC Report No. 6-75-65-55.
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- (6) "Independent Research Report for 1958," LMSD Report No. 49704; p 20, "Stability and Post-Budding Behavior of Curved Elements."
- (7) "Independent Research Report for 1959," LMSD Report No. 288164; p 64, "Structural Stability."
- (8) "Independent Research Report for 1963," LMSC Report No. 5-13-63-1; p 122, "Shell Stability."
- (9) "Independent Research Report for 1964," LMSC Report No. 5-13-65-2; p 156, "Stability Analysis."
- (10) "Independent Research Report for 1965," LMSC Report No. 5-13-66-5; p 130, "Continuum Mechanics."
- (11) Private Communication, L. Schapiro.
- (12) "Anisotropy of Young's Modulus in 18% Nickel Maraging Steel," R. E. Lewis, AF Mat'l Lab. Report No. RTD-TDR-63-4048, p 369 (Nov. 1963).
- (13) "Fracture Toughness in Plate Thicknesses of 18% Nickel Maraging Steels," R. E. Lewis, AF Mat'l Lab. Report No. RTD-TDR-63-4048, p 387 (Nov. 1963).
- (14) "Large Booster Weight Comparison, Glass Filament and Steel," L. Shapiro, E. Morris and O. Hoffman, Bull. Interagency Solid Propulsion Meeting, Addendum 4, 17 (July 1963).
- (15) "Study of Advanced Materials and Designs for Deep Submersible Hulls," LMSC Report No. A034248, May 1964.

INTERDEPARTMENTAL COMMUNICATION

TO W. C. Griffith DEPT./ 52-01 BLDG./ 201 PLANT/ 1 DATE July 29, 1966
ORGN. ZONE FAC.

FROM R. G. Davis DEPT./ 55-01 BLDG./ 102 PLANT/ 1 EXT. 2-1447
ORGN. ZONE FAC.

SUBJECT: IMPACT OF IMSC INDEPENDENT DEVELOPMENT

During 1963 and in prior years, the IMSC Independent Development program was small and did not exert a major influence on new systems. One program which was affected by ID during this period, however, was the Reactor In-Flight Test (RIFT) Program. In-house work in large structures, supports and stiffeners contributed measurably to IMSC competence. Subsequent to that time, Independent Development projects have provided a large element in the development of many IMSC programs; the following are examples:

Program 461:

The special payload development Project 1612, undertaken in 1964, proved the feasibility of several new concepts which greatly enhance missions capabilities. Program 461 and other related Air Force space programs in which IMSC is involved have been significantly influenced by this development. In late 1965, new ID activities were undertaken to improve power, attitude control, and sensor subsystems for high-altitude military satellites of this type--their results have already had some influence on IMSC contracts and are expected to have more.

Deep Submergence
Rescue Vehicle
(DSRV):

The Ocean Systems Independent Development brought out the basic pressure-hull structure and material concept which is employed in the in-house Deep Quest project as well as the DSRV project. Likewise, the Integrated Control System provides the needed hover and maneuver capability. Without these developments the DSRV would be a very different vehicle. Beyond doubt these and the other Ocean System ID efforts were vital factors in the IMSC success in the completion.

P-65:

IMSC Independent Development projects dating back to 1965 have attacked the large structure problems associated with a 10-foot diameter upper stage for Titan-class vehicles. In consequence of this work, a modular design now exists for a versatile Control Section vehicle with secondary propulsion attitude control, auxiliary power, telemetry and command functions in many payloads. During the last year the Independent Development program has brought out a new attitude control subsystem including an analog channel for rapid response and digital channel for efficiency and precise control; in combination they provide a significant advance in long-life, high-performance active attitude control. These developments have asserted an important influence on the Government space program involved and on IMSC business.

Cryogenic Upper Stage: IMSC has been doing Independent Development in super-insulation and the fluid mechanics of cryogenic propellants since 1963. It is now carrying this work forward to the point of subsystem development for a cryogenic upper stage. Although no major new system exists as yet, program planning at NASA Laboratories (LeRC, MSFC) is being influenced significantly by the work being done under IMSC Independent Development. In addition, IMSC has had almost \$6 million of contract funding, principally with these same agencies, which is further influencing Government planning for next-generation upper-stage vehicles. This Independent Development work has also established a strong capability at IMSC to serve as prime contractor for such stages.

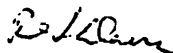
Special Projects: Each year IMSC has reserved funding under Independent Development to carry out key development work for special military satellite projects. These have contributed significantly to the IMSC payload integration and data acquisition capabilities. Accordingly, they have made it possible to carry out new missions.

In addition to the above projects which are regarded as significant influences on major systems, one can cite examples of IMSC technology developments which are influencing Government programs and contributing to the state of the art in a manner of vital interest to the Government. Examples of this type include:

**Data Compression:
and Advanced
Telemetry** IMSC has carried out Independent Development in Data Compression and in the technologies related to its mechanization in terms of vehicle ground station electronics. Over \$1 million in contracts with NASA (MSFC, GSFC and ARC) has been booked and several equipments built to support in-house programs. The concept of Memory programmed commutation and decommutation, which evolved in the course of PCM Ground Station and UHF/PCM Instrumentation projects, is now the standard in the field.

**Subliming Solid
Attitude Control:** The use of a subliming solid as a source of attitude-control thrust was pioneered at IMSC and important work done under Independent Development. Present outside contract work now totals \$1.5 million, and a significant impact has been made on stabilization techniques for long-life spacecraft.

**Advanced Life Support
Systems:** Under Independent Development, IMSC evolved a new concept in two-gas life support. This work, now being continued in part under NASA MSC funding, is expected to play an important part in future manned spacecraft programs.


R. G. Davis

GRUMMAN AIRCRAFT ENGINEERING CORPORATION

BETHPAGE, LONG ISLAND, NEW YORK 11714

CABLE ADDRESS
GRUMAIR



December 1, 1966

Mr. E. B. Harwood
Office of the Director of Defense
Research and Engineering
The Pentagon
Room 3D 1028
Washington, D. C. 20301

Dear Mr. Harwood:

We are pleased to forward information on a number of specific IR & D programs which have an output beneficial to DOD. These data follow the outline supplied in a letter by Mr. Phillips, Task Group Chairman.

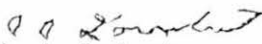
Although specific detailed examples of benefits can be cited and are enclosed, the major benefit of DOD's IR & D program is more likely raising the level of technical competence of the entire aerospace industry. The successful deployment of a major weapons system not only is the product of the specific team that developed the system but also owes its success to the many and varied inputs provided by the entire aerospace industry through publications, presentations and dimensions. These inputs, although indirect, provide chain reactions of ideas, many of which find their way into the new products of the DOD effort.

The examples enclosed include several which have direct benefits to DOD in improving the cost effectiveness of our manufacturing process.

If we can be of further assistance, please let us know.

Sincerely yours,

GRUMMAN AIRCRAFT ENGINEERING CORPORATION


A. A. Lambert
Manager of R & D Programs
Business Development Department

Enc.

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GRUMMAN AIRCRAFT ENGINEERING CORPORATION

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SELECTED IR & D-FUNDED PROGRAMS BENEFICIAL TO DOD

Hot Forming of Titanium

- A. Significance: Titanium sheet (8% Mn, Ti) can be hot-formed for relatively simple contours with one handling. A unique design modification of a hot-forming press eliminates the costly and time-consuming pre-form step.
- B. Benefit to DOD: This new technology holds excellent promise for one-pass forming of more severe curvatures of titanium structural sheet. The Air Force Materials Laboratory is now funding a continuation of this program as a promising manufacturing process for Supersonic Aircraft and Space Vehicles.
- C. Date Started: 1964
- D. Dollars Spent (IR & D): 10,000 hours \$100,000

Advanced Chemical Milling Techniques

- A. Significance: Advancement in the technology of chem-milling of titanium, refractory alloys and stainless steel and the refined chem-milling of aluminum has resulted in better control of thickness, finish, and tolerance as well as more complete masking using flow-coat and electrophoresis techniques.
- B. Benefit to DOD: Powerful fabrication techniques for fast, low-cost production of complex contours are provided by the new technology coming out of this project. The Air Force Materials Laboratory is now funding a continuation of this program.
- C. Date Started: 1960
- D. Dollars Spent (IR & D): 25,000 hours \$250,000

Improved Magnetic Detection of Submarines

- A. Significance: Detection range has been increased by about 40 per cent through a reduction by a factor of 5 of the noise level of the flux-gate magnetometer.
- B. Benefit to DOD: This represents a major breakthrough in ASW-sensor development. The increased MAD reliability, maintainability and performance give greater effectiveness in submarine hunting and killing, and has application to overland detection of vehicles, artillery, supply dumps and rifle caches.

C. Date Started: 1961

D. Dollars Spent (IR & D): 20,000 man hours \$200,000

System Optimization Research

A. Significance: Optimization techniques originated by Grumman have received wide recognition in the scientific community and the aerospace industry. The techniques have applications to semiconductors, optimum antenna arrays, optimum orbital transfers, control of reentry vehicles, interplanetary trajectory determination, aerospace vehicle performance and navigation.

B. Benefit to DOD: These techniques aid DOD contractors in obtaining the best possible performance from weapons systems and their component subsystems. For space travel and long-range missiles, relatively small differences in performance are critical to the achievement of major goals.

C. Date Started: 1963 (for area discussed)

D. Dollars Spent (IR & D): \$290,000 (assumed to be 50% of the \$585,000 expended for flight mechanics)

Cryogenic Quenching of Production Parts

A. Significance: This process in which aluminum alloys are quenched in liquid nitrogen from a solution heat-treating temperature of about 900°F produces distortion-free parts. Several aluminum alloys in gauges up to and including 0.125 inch have been tested, and 2014, 2219, and 6061 are now being quenched on a production basis.

B. Benefit to DOD: The process contributes significantly to cost reduction since it permits aluminum alloy parts to be formed and heat-treated in a minimum number of steps without distortion.

C. Date Started: 1964

D. Dollars Spent (IR & D): \$100,000

Hypersonic Aerodynamics Research

A. Significance: Grumman's work in hypersonic aerodynamics is well known in the aerospace industry. More than 25 Air Force and Navy reports have been published and widely distributed. The data on the use of transverse jets for control are the only data currently available for Mach numbers above $M = 10$. GAEC vehicles have influenced the experimental programs of government and industry.

- B. Benefit to DOD: The control of very high-speed aircraft and reentry spacecraft will be a critical area for future operational systems. These pioneering efforts contribute greatly to the level of technical competence of the DOD team in this area.
- C. Date Started: 1963 (for area discussed)
- D. Dollars Spent (IR & D): \$170,000 (taken as $\frac{1}{2}$ of the \$515,000 devoted to aerodynamics research)

Aircraft Crew Escape System

- A. Significance: Rocket-seat positioning and ballastic parachute spreading has extended seat escape down to zero altitude and 25 knots.
- B. Benefit to DOD: Speed, altitude and altitude survival envelopes for aircraft crew emergencies have been extended down to the extremely difficult conditions of very low altitude (including takeoff and landing), low speeds and adverse aircraft attitudes.
- C. Date Started: 1966
- D. Dollars Spent (IR & D): \$15,000

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RAYTHEON COMPANY

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RAYTHEON SUBMISSION OF PAYOFFS IN IR&D

An examination of our IR&D efforts falls into four broad categories:

- 1) Get ready for well-defined programs in the near future;
- 2) Provide continuity for Government-funded programs where conditions are such that Government funding would put hills and valleys in the effort curve;
- 3) Extend present technique and hardware, where they have been space- or ballistic-missile-qualified, to new systems which are outgrowths of the older ones;
- 4) Continue efforts essential to company growth, where temporarily the Government is supporting other people for similar work.

It is instructive to look at one company's examples in each area as follows:

Space-Fed Phased Array Antennas

By 1962 it became clear that the next-generation radars would use phased array antennas.

A study in that year examined the tradeoff considerations among corporate-fed, series-fed and space-fed phased arrays. Practical experience in that time period was largely with corporate-fed techniques, and the resulting antennas, though flexible and allowing many simultaneous beams, were costly and had pattern and interaction problems. The trade-off study aimed somewhat at cost, maintenance and interaction problems concluded that the space-fed approach showed the most promise. To gain experience and understand the technical risks of this choice, a one-hundred-element array, beam steering computer, feed collimation correction program were undertaken in the 1963 IR&D program.

Toward mid-1963, the NIKE-X program became serious about a Missile Site Radar (MSR)—a lower cost agile beam radar—and issued RFP's to industry in October 1963 to be returned November 15, 1963.

The IR&D program, which by the had illuminated many of the seen and unseen problems of the space-fed approach, provided the technical base against which to make a competent response in the six weeks allotted.

In fact, the hard technical data and the depth with which the risks and their solutions were understood, allowed Bell Labs to make a decision on this program in December 1963, just six weeks after proposal submission. Work started January 2, 1964.

Not only did the program start promptly, but the resulting radar will require less maintenance and logistic support in the field and will cost several million dollars less than one built around corporate-fed techniques.

It is likely that space-fed techniques for MSR would have evolved without the IR&D program, but it is generally agreed that the time saving to this program is the order of one year as a result of the IR&D effort.

OHD (Over-the-Horizon Detection)

In the late 1950's, Raytheon scientists, who had been studying high-frequency propagation (some funded, some IR&D) for some years, concluded that forward-scatter over-the-horizon detection of incoming enemy ballistic missiles might be possible. If possible, the cost saving over other methods was such that the possibility could not be overlooked.

After a short time, their theoretical efforts were rewarded with Air Force contracts and a normal development cycle began. By 1962, contracts in the order of \$1.5M were activated. Raytheon people, who were close to the project, became more optimistic, but the complexity of the physics involved naturally produced conservatism in many quarters. As a result, Government money, to get ready for the next phase, was short.

Rather than debilitate the required effort, an IR&D program, initiated in the latter part of 1962 and continuing to mid-1963, maintained the manpower level on this problem so that, by September 1963, when the Air Force was able to provide a nearly \$13M contract, the program could be prosecuted in an orderly manner.

POSEIDON

A most important aspect of the high reliability achieved by the Polaris guidance computer program resulted from the use of welded circuit modules

and their resultant packaging method. That technology and the manufacturing processes developed earlier in IR&D programs were available to be used at the outset for the design of the Digital Differential Analyzer (DDA) required for that weapon system.

Starting with the 1963 IR&D program, extensive development went into an examination of how new packaging concepts and components could be applied to a new-generation guidance computer. In addition to the circuit work, a program examining the tradeoff aspects of multiple warheads was undertaken, and by 1964 included the effects such a system might have on the guidance computer.

This latter program led to a publication which resulted in an association between MIT and Raytheon which concluded, among other things, that a DDA would be unsuitable for the accuracy and flexibility desired in a follow-on system. A general-purpose digital computer evolved and, coupled with the new packaging techniques, became the basis for the Poseidon computer by April 1965.

MIT and Navy confidence in the packaging and quality-assurance methods extrapolated from Polaris, coupled with the IR&D work on targeting, probably resulted in the saving of a year to the Poseidon Guidance Computer.

SAM-D

An important segment of our Company business is the air defense business. In the spring of 1963, the Army instituted competitive feasibility studies for an air defense system for the 1970's (AADS-70's). That feasibility study was submitted to the Army in September 1963, and in January 1964 we learned that we had lost the competition and the Army was proceeding with two other contractors. Determined to continue in this area, the 1964 IDP program provided design and hardware construction for key elements of an advanced ground-to-air missile system. The program undertaken was to actually build and flight test a TVM sample data homing guidance system. The hardware portion included a TVM down link and the high-voltage power supply for the TWT, an inverse receiver design missile seeker that could operate on sample data, a phased array radar that could track four targets simultaneously while providing target illumination and search functions, lightweight electrical missile head and actuator, control grid amplifiers,

solid state local oscillators, and radomes to withstand the high temperature and rain erosion for the higher velocity missile.

As things developed, the Army concepts for the new air defense weapon matured into its surface-to-air missile development (SAM-D), and in April 1966 industry was solicited for a competitive CDP. The responses were due June 1966. The IR&D efforts which were maintained from 1964 through 1966 were recognized by the Army when they awarded Raytheon one of the competitive CDP's in August 1966.

LITTON INDUSTRIES, INC., 9370 SANTA MONICA BOULEVARD • BEVERLY HILLS, CALIFORNIA 90213

14 December 1966

FRED W. O'GREEN, SENIOR VICE PRESIDENT

Office of the Director
of Defense Research and Engineering
Room 3 D 1028
The Pentagon
Washington, D.C. 20301

Attention: Mr. E.B. Harwood

Reference: Letter to Mr. Charles B. Thornton from
Mr. Thomas L. Phillips

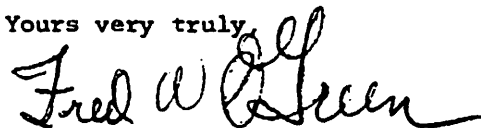
Gentlemen:

Mr. Phillips' recent letter to Mr. Thornton requesting information for the Defense Science Board's study of Independent Research and Development has been passed on to me for reply. We have chosen four representative samples of our IR & D programs which have or will have had direct benefit to the Department of Defense; and attached the descriptions in the format suggested by the referenced letter.

We should like to point out that, in general, benefits in terms of time and cost saving, technological advancement, etc. require in excess of three years for operational realization; but that the eventual impact can be fairly accurately predicted within that period of time, which has lent itself to the analyses which are attached.

We must apologize for our delay in answering Mr. Phillips' letter and hope that it will not cause you undue inconvenience. In the event you desire additional information or clarification of the information which is attached, please call upon us.

Yours very truly,



Attachments

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CASE 1

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Date: MAR 08 2011

TITLE: P500 Platform

INITIATED: FY '64

COMPLETED: FY '65

IRAD BROCHURE IDENTIFICATION: FY '65; Development Project 2-G
Simplified Inertial System Development

TOTAL EXPENDITURES: \$442,000

COST SHARING: 50% from Litton Profits
50% Assigned to the G & A Burden of the Guidance & Control
Systems Division

The objective of this IRAD project was to develop an inertial platform suitable for navigation and altitude reference applications in military aircraft which represented a very significant advancement in the inertial platform technology. Improvements in accuracy, reliability and maintainability were sought concurrent with the reduction in size and weight demanded by advanced military aircraft. Low production cost was a major consideration.

The degree of success of this project can be demonstrated by comparing the salient characteristics of the P500 platform with its predecessors, the P200 series of platforms which has found very wide application in military aircraft.

In the P500 platform a weight reduction of 50% and a volume reduction of 60% over the P200 were achieved. The improvement in reliability is in the order of 3 to 1 and accuracy was increased by a factor of 2 to 1.

The P500 platform features segmented gimbals to facilitate servicing and reduce production and maintenance costs. Built in flexibility permits the platform to accept various Litton inertial instruments with minimal changes. Reliability and maintainability improvement was achieved by replacing the P200 gear driven gimbal system with direct drive torquers in the P500 and by simplifying and integrating the platform electronics with the platform. The warmup rate of the platform has been improved by 70% over the P200 to decrease the reaction time of combat aircraft. The full extent of savings cannot be evaluated until further production has been achieved.

IRAD funding carried this development through the crucial breadboard stage. After further development this advanced platform was chosen as a part of the SRAM carrier vehicle avionics equipment.

CASE 2

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TITLE: C220 Computer

INITIATED: FY '64

COMPLETED: FY '65

IRAD BROCHURE IDENTIFICATION: FY '64 and FY '65; Project 1G
Advanced Computer Development

TOTAL EXPENDITURES: \$237,000

COST SHARING: 50% from Litton Profits
50% Assigned to the G&A Burden of the Guidance &
Control Systems Division

The objective of this IRAD project was to develop an advanced computer meeting military specifications and incorporating the latest advances in technology to provide a superior means of solving the airborne navigation problem with minimum computer complexity, size and weight.

The type of computer that resulted from this research and development project was an advanced digital differential analyzer. It represents a complete departure from the analog type of computer heretofore used by Litton for this application. Comparison of the C220 to the predecessor type of computer shows a reduction in weight by a factor of 5 to 1 and a reduction in volume by a factor of 4 to 1. The computation performance is such that the computer's error contribution to overall system performance is completely negligible. In addition to these accomplishments, a substantial reduction in unit cost can be projected for comparable production quantities. The full extent of the savings cannot be evaluated until further production has been achieved.

The IRAD funding carried this development through the breadboard stage. After further development this computer was chosen for two classified military programs.

CASE 3

Page determined to be Unclassified
Reviewed Chief, RDD, WHS
IAW EO 13526, Section 3.5
Date: MAR 08 2011

TITLE: Low Altitude Altimeter

INITIATED: FY '64

COMPLETED: FY '66

IRAD BROCHURE IDENTIFICATION:

FY '65; Development Project 5 AM, Development of an Advanced
Low Altitude Altimeter

FY '66; Development Project 1 AM, Operational Altimeter with
Solid State Source.

FY '66; Development Project 2 AM, Advanced Military Altimeter

TOTAL EXPENDITURES: \$270,000

COST SHARING: 50% from Litton Profits
50% Assigned to the G&A of the AMECOM Division

IRAD PROJECT ACHIEVEMENTS

1. Development of an all solid state system including the replacement of a Klystron with a solid state power supply.
2. Development of an all electronic (solid state) system to replace an electro mechanical servo system involving a motor driven shaft.
3. Increased reliability.

BENEFITS TO THE DOD RESULTING FROM THE EFFORT:

Litton recently won a procurement competition to supply several hundred low altitude altimeters for the upcoming C5A aircraft. The previous large order for this type of device was a Low Altitude Sensing Device (LASD) provided for the Navy. Comparisons of LASD with the C5A Altimeter follows:

1. LASD used hybrid (tubes and solid state devices) circuitry. The C5A uses only solid state circuitry including the replacement of the klystron in the power supply.

CASE 3, Continued

2. LASD used an electro mechanical motor driven shaft. This device was replaced by electronic circuitry in the C5A altimeter.
3. The weight and volume of the C5A altimeter are about 50% less than for the LASD.
4. The C5A altimeter is accurate to "touch down" whereas the minimum altitude required by the LASD was 30 feet.
5. Overall system reliability is greater for the C5A altimeter.
6. The C5A includes additional inline monitoring and logic to constantly check itself for specified accuracy.
7. The above listed improvements and additional features were achieved with no appreciable increase in per unit cost.

CASE 4

Page determined to be Unclassified
Reviewed Chief. RDD, WHS
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Date: MAR 08 2011

TITLE: Microelectronic Computer, L-300 Series

INITIATED: FY '64

COMPLETED: FY '66

IRAD BROCHURE IDENTIFICATION:

FY '64; Development Project 50 - Ultra High Speed Microelectronic
Computer Development

FY '65; Development Project 1D - High Speed Computer Development

FY '66; Development Project 3D - High Speed Computer Development

FY '66; Development Project 4D - 8192 Word Memory Development

TOTAL EXPENDITURE: \$604,000

COST SHARING: 50% From Litton Profits
50% Assigned to the G&A Burden of Data Systems Division

PROJECT ACHIEVEMENTS:

A high speed ultra reliable microelectronic computer was developed. New logic circuits and computer packaging techniques provided a distinct advancement in the state of the art of computer technology. High reliability and ease of maintenance along with small size and weight make this computer especially attractive for immediate application to present and forthcoming requirements for mobile tactical data processing and avionics equipments.

BENEFITS TO THE DOD:

The L304 computer from this family is under contract for inclusion in the Army's Tactical Data Processing System (TADPS), the Navy's Airborne Tactical Data System (ATDS), the Canadian Command and Control System 280, and is being proposed for the Air Force 407L Tactical Command and Control System.

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H O N E Y W E L L
I N C.

Page determined to be Unclassified
Reviewed Chief, RDD, WHS
IAW EO 13526, Section 3.5
Date: MAR 08 2011

C. L. DAVIS
Vice President

November 23, 1966

2747 Fourth Avenue South
Minneapolis, Minnesota 55408

Mr. E. B. Harwood
Room 3D-1028
Pentagon
Washington, D. C. 20301

Dear Mr. Harwood:

I am forwarding a number of examples of the output of Honeywell's Independent Research and Development Program for the past three years, which were recently requested by Mr. Thomas L. Phillips. The benefits to the Government which are cited in the examples include technological breakthroughs, cost savings, higher reliability, reduction in size and weight and overall operational effectiveness.

IR&D funds at Honeywell are spent primarily to meet Government technology and hardware requirements projected for the period two to five years subsequent to expenditure. Major production quantities may follow the IR&D effort by up to eight years. Since Mr. Phillips requested outputs from the IR&D program conducted during the past three years (1964 through 1966), the results of the attached projects, in many instances, are projected and cannot be stated as quantitatively as would be possible after another two to four years. You will probably find this true of the data you obtain from other contractors. This problem might be solved by preparing outputs from the past five or six years' IR&D effort. On the other hand, since available records may be the controlling factor, you might wish to develop the initial data with the above limitation in mind, and update the list annually showing the improvement in payoff for three to four years before the project is dropped from your list.

We are glad to provide the attached information, and will be happy to cooperate with you in any approach which you might wish to take.

Very truly yours,



Enclosures

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TITLE: AUTOMATIC WEAPON FUZES

BRIEF DESCRIPTION: This program was started in 1963 and completed in 1964. It is identified in the 1963 IR&D brochure under Advanced Fuzing - Ammunition Fuzing¹ and in 1964 under Advanced Ammunition Fuzing². Approximately \$20,000 of IR&D (of which the Government paid for \$15,000) was applied to fuze development for 20, 30 and 40mm ammunition. This fuzing effort was successful in meeting such special requirements as small size, delayed arming, superquick fuze functioning, very high spin rates and unusual setback forces. As automatic weapon muzzle velocities and spin rates increase, forces which the fuze must withstand increase beyond the capability of existing fuzes. This fuze design has successfully survived this extreme environment while fulfilling the performance requirements.

BENEFITS TO THE DOD RESULTING FROM EFFORT: Initial application of this fuze was to the WECOM 30 Weapon System for helicopter armament. Subsequent application was to the 20mm self-destruct round for the Hispano Suiza 820 gun used in the Vehicle Rapid Fire Weapon System (VRFWS). Contract effort on these two fuzes to date totals \$125,000. Although follow-on effort for the WECOM 30 application was not obtained by Honeywell, we are anticipating further development funds on the 20mm application in the amount of \$425,000 for Phase II development. An additional \$400,000 for Phase III would be required to complete the development. This fuze also has application to the 20mm rounds for the Vulcan weapon. The low-cost feature makes it particularly adaptable to ammunition of this type which is consumed in high quantity. Production potential of both applications is extremely high, inasmuch as both weapons employ automatic fire. The total potential production requirements for the Hispano Suiza fuze is approximately \$40,000,000 over the next five to seven years and for the Vulcan fuze is approximately \$30,000,000 over the next six to seven years. The probability is high that this fuze will be placed in production for the above two applications.

¹Honeywell Ordnance Division Development Program 1963, Vol. II of IR&D, dated 1 January 1963, p 15 (Confidential).

²Honeywell Ordnance Division Development Program 1964, Vol. II of IR&D, dated 15 April 1964, p 43.

TITLE: MASS FOCUS STUDY

BRIEF DESCRIPTION: This program was conducted in 1965. In the IR&D brochure for 1965 it is identified under Advanced Kill Mechanisms - Anti-personnel Munition.¹ Approximately \$40,000 of IR&D (of which the Government paid for \$30,000) has been applied to this investigation. The mass focus principle was discovered within the Air Force and investigated in relatively large sizes. This program was directed toward its application to small bomblets both in the anti-materiel and anti-personnel mode. Both disc and cylindrical shapes were evaluated and found to contribute to increased effectiveness. Much of the work was experimental to determine the relative effects of parameter variation associated with the many elements of the test configurations.

BENEFITS TO THE DOD RESULTING FROM EFFORT: There is a continuous search for better kill mechanisms to increase weapon effectiveness. The mass focus principle offers potential, particularly in the anti-materiel mode, for being a successful result of this search. Its focusing capability for directing the explosive effect in a narrow beam allows materiel penetration much greater than that which can be achieved by an equivalent quantity of high explosive in a more conventional configuration. It has greater standoff characteristics than the shaped charge and is not as sensitive to orientation. Although the penetrations are not as deep as the shaped charge, they are quite spectacular when applied to non-armored materiel targets. The Air Force has awarded Honeywell three contracts which utilize the results of the mass focus investigation conducted under this IR&D program. The contracts are the Mass Focus Weaponization Study, the Area Denial Study (1966) and the Anti-materiel Bomb. The total dollar value of these three contracts is \$456,000. A plan for the continuation of the Anti-materiel Bomb development is currently being evaluated by the Air Force. This Phase II program has been proposed for \$500,000. In addition the Air Force has a stated requirement for a Light Vehicle Mine. Proposal effort is currently underway. The most efficient kill mechanism for this application utilizes the mass focus principle.

¹ Honeywell Ordnance Division Independent Development Program 1965, Vol. II of IR&D, dated 15 April 1965, p. II-4.

TITLE: SHAPED CHARGE

BRIEF DESCRIPTION: This program was started in 1963 and concluded in 1964. In the IR&D brochure for 1963 it was identified under Advanced Weapons - Shaped Charge Ammunition¹ and in 1964 under Advanced Kill Mechanisms.² Approximately \$47,000 of IR&D (of which the Government paid for \$35,000) has been applied to the area of small shaped-charge ammunition. Shaped charges as small as one inch in diameter were evaluated for their penetration capability. Fabrication techniques, including the application of powdered metal liners, were also investigated. Results were very encouraging and led to the successful application of the powdered metal liners to the Rockeye II bomblet.

BENEFITS TO THE DOD RESULTING FROM EFFORT: The Rockeye II requirements demanded exceptional penetration of extremely hard armor with a relatively small shaped charge, two inches in diameter. The small-sized bomblet was necessary to maximize the number of bomblets per system to achieve a high hit probability on the tank targets. Although accurately machined liners would accomplish the desired results, they would be costly to produce. The shaped-charge technology acquired through this IR&D project, together with the success of the powdered metal techniques to achieve accurate low-cost liners, has resulted in the fulfillment of the requirement for the Rockeye II bomblet. To date \$5,000,000 of contract funds have been expended and committed toward the development of the Rockeye II System. It is conservatively estimated that the outstanding performance of this system will result in \$100,000,000 of production over the next five years.

¹Honeywell Ordnance Division Development Program 1963, Vol. II of IR&D, dated 1 January 1963, p 36 (Confidential).

²Honeywell Ordnance Division Development Program 1964, Vol. II of IR&D, dated 15 April 1964, p 26.

TITLE: HELMET SIGHT SYSTEM

BRIEF DESCRIPTION: In January of 1964 Honeywell began to invest IR&D funds to develop a helmet sighting system that would enable utilization of a pilot's (or observer's) eyes as an integral part of airborne weapon systems. Since then, \$250,000 (of which the Government paid for about \$180,000) of IR&D was invested. In the IR&D brochure, this program was identified as Helmet Sight System.¹ The unique Helmet Sight System provides for a pilot's line of sight with respect to the aircraft frame of reference to be determined without mechanical linkages to the helmet. The basic technique for a helmet-sight-position (azimuth and elevation) pickoff system uses sweeping fans of collimated light to trigger responses from photo-diodes attached to the helmet sight. The signals are processed by a small computer to provide azimuth and elevation angles of the pilot's line of sight with respect to the aircraft's reference-coordinate system. Laboratory tests indicate that the sweeping-fan light technique is capable of measuring helmet-sight angles to an accuracy of 0.1 degree.

BENEFITS TO THE DOD RESULTING FROM EFFORT: This system currently provides technological breakthroughs which allow a pilot wearing the sight system to be unencumbered by any mechanical linkages to his helmet and to be unrestricted in his movements in the cockpit. In addition, it is the only system capable of being used operationally today, according to the Army—which view is largely shared by the Air Force. It is being furnished for the AAFSS weapon development program under contract as of June 1966, with deliveries scheduled to begin mid-1967. In five separate competitions, it was selected for proposal by prime aircraft and armament system contractors.

Current proposals to the Air Force and Army show using the sight as a key element for quick-accurate fire control and reconnaissance systems. Other uses include ground fire control for surface-to-air weapons, shipboard fire control for Naval armament, airborne updating of navigation location, low-level bombing systems, etc.

¹Honeywell Ordnance Division Independent Development Program 1966, Vol. II of IR&D, dated 1 September 1966, p III-50.

TITLE: RADAR LANDING AID (STATE)

BRIEF DESCRIPTION: The Honeywell-developed STATE (Simplified Tactical Approach and Terminal Equipment) is a C-band pulsed instrument landing system which provides azimuth and elevation guidance information to an aircraft from a minimum acquisition range of ten nautical miles to touchdown. STATE is a new-generation, highly portable landing system weighing only 70 pounds that is capable of providing guidance data to up to 100 aircraft simultaneously.

The program is identified in the IR&D brochures as indicated in the notes below¹; \$135,000 has been spend on the project (of which the Government paid for about \$100,000).

BENEFITS TO THE DOD RESULTING FROM EFFORT: The STATE system is a light-weight, reliable, all-weather landing system designed for tactical use. It uses a combination of pulsed guidance lobes and pulse leading-edge tracking techniques in contrast to ILS C-W systems, which result in substantial improvements in guidance beam linearity. This improvement is particularly notable at low glide-slope elevation angles where severe beam perturbations are frequently encountered with conventional ILS. Also, in contrast to current ILS, STATE provides continuous range-rate information, obviating the need for auxiliary marker beacons to indicate distance to touchdown. The system is pilot oriented, and a highly trained ground crew such as is used for GCA is not required. A significant feature of STATE is the use of broad fixed beams to provide a wide acquisition gate. This feature is essential for aircraft operating under tactical conditions without prior knowledge of the precise location and orientation of the ground station. Honeywell was placed under contract by the Air Force in 1965 and initial production units are scheduled for early 1967. The initial military sales alone of STATE are estimated to be \$175-\$225 million over the next 8 to 10 years.

¹ Honeywell Aeronautical Division Independent Development Program 1965, Vol. III - Part 1, dated 15 April 1965, pp 2-229 and 2-230.

Honeywell Aeronautical Division Independent Development Program 1966, Vol. III - Part 1, dated 1 September 1966, pp 91-93.

TITLE: MICROELECTRONIC AUTOPILOT DEVELOPMENT

BRIEF DESCRIPTION: Over the past three years Honeywell has invested approximately \$375,000 of IR&D funds (of which the Government paid for about \$275,000) in the development of microelectronic techniques for autopilots. In the IR&D brochures for 1964, 1965 and 1966, this program was identified as indicated in the note below.¹ This investment complements a larger (over \$750,000, of which the Government paid for about \$550,000) IR&D investment in microelectronic techniques for broad aerospace application over the past eight years.

This development was directed at obtaining the maximum benefits of microelectronics packaging through standardizing as much as possible on the number of individual microelectronic elements. The microelectronic packaging development resulted in Functional Electronic Blocks that interconnect the microcircuits on ceramic substrate subassemblies to develop the required electronic functions. The interconnection networks on the ceramic substrate utilize a reflow soldering technique to conductive pads. Some two-thirds of the required electronics functions were converted to microelectronic chip elements through this development.

BENEFITS TO THE DOD RESULTING FROM EFFORT: Microelectronic packaging is an improvement over discrete-component solid state packaging when comparing reliability, cost, and size/weight. The new microelectronic packaging techniques permit a 15% reduction in the cost and a 14% increase in reliability when compared to the prior design with solid state discrete components.

The Functional Electronic Blocks that resulted from this development have been applied in contracts for autopilots for the C5-A Transport Aircraft and the AAFSS Rotary Wing Aircraft, and are projected for use in autopilot standardization programs for both Army and Navy Aircraft. These contracts have an initial funding level of over \$7 million. The standard microelectronic autopilot can also be expected to extend to the SST, Hypersonic Aircraft and other applications in the coming months.

¹ Honeywell Aeronautical Division Development Program 1964, Vol. III of IR&D, dated 15 April 1964, pp 2-156, 2-162, 2-165 and 2-166.

Honeywell Aeronautical Division Development Program 1965, Vol. III - Part I of IR&D, dated 15 April 1965, p 2-211.

Honeywell Aeronautical Division Independent Development Program 1966, Vol. III - Part I of IR&D, dated 1 September 1966, p 71.

TITLE: PROXIMITY FUZE

BRIEF DESCRIPTION: This program was started in 1965 and concluded in 1966. In the IR&D brochure for 1965 it was identified under Advanced Fuzing - High Effectiveness Fuzing¹ and in 1966 as Proximity Fuze Electronics.² Approximately \$115,000 of IR&D (of which the Government paid for \$86,000) has been applied to this investigation of proximity fuzing for bomblets and small projectiles. The emphasis has been placed on miniaturization and low fuze cost through the medium of microcircuit application. Burst heights of 2 to 10 feet, heretofore achieved only by complicated mechanical rebounding mechanisms, have been attained in a fuze size comparable to existing impact fuzes. The application of microcircuits has reduced costs and improved performance over discrete component circuits.

BENEFITS TO THE DOD RESULTING FROM EFFORT: The results of this effort have been applied in two areas, small bomblets and the 2.75-inch rocket.

First, in the past, the large fuze size and high cost leading to poor cost effectiveness prevented the use of a proximity fuze for small bomblets. In this instance, the results of this IR&D have been applied to the BLU-26 bomblet to satisfy the bulk dispenser requirements of the Air Force. The BLU-26 is a self-dispersing munition, currently impact-fuzed, whose effectiveness can be substantially increased by providing a relatively low airburst capability. To achieve the full benefits of the improved effectiveness, it is necessary to attain a proximity-fuze size comparable to that of the existing impact fuze. This objective has been reached, and a \$138,000 contract for continued development has been awarded to Honeywell by the Air Force. The projected fuze cost of under \$10.00 is substantially less than the cost of proximity fuzes currently in existence. An additional \$650,000 would be required to complete development and flight test. The large requirements for bulk-dispersed munitions for the Air Force, together with lesser requirements by both the Army and the Navy, could lead to substantial production for this fuze. Production volume could reach \$100,000,000 over the next five to six years.

Second, the program results were also applied to the proximity fuze for the 2.75-inch rocket. Here the emphasis was on the microcircuit application to the fuze design for cost reduction. Honeywell was working on a development support contract for a discrete-component fuze. Late in the contract, the advantages of substituting a microcircuit package acquired under the program were realized. This substitution has been approved by the contracting agency and will result in at least a \$3.00-per-fuze saving during high production. With an anticipated production rate of 600,000 annually, a total savings of \$1,800,000 per year can be realized. In addition fuze performance was improved.

¹ Honeywell Ordnance Division Independent Development Program 1965, Vol. II of IR&D, dated 15 April 1965, p II-26.

² Honeywell Ordnance Division Independent Development Program 1966, Vol. II of IR&D, dated 1 September 1966, p III-20.

TITLE: LASER GYRO

BRIEF DESCRIPTION: Over the past three and one-half years, Honeywell has invested approximately \$600,000 (of which the Government paid for about \$440,000) of IR&D funds in the development of the laser gyro for guidance, navigation and other applications. In the IR&D brochure for 1964, 1965, and 1966, this program was identified as indicated below in the notes.¹

The resonant cavity of a laser gyro consists of three or more reflectors. These form a closed path for radiation traveling in each direction around the path. A laser oscillator then operates in each direction. When the cavity is rotated about an axis, which is perpendicular to the plane of the path, the cavity tunes to different frequencies and in two directions. The oscillators then operate at different frequencies. The two output radiations are brought together on a photosensor and, by interference, produce a signal having a frequency proportional to the input angular velocity.

BENEFITS TO THE DOD RESULTING FROM EFFORT: The laser gyro designed with no moving parts affords lower cost, faster ready time and less vulnerability to shock and vibration when compared with the more conventional designs such as gas bearing gyros, floated gyros and electrically suspended gyros that have been used in prior guidance and navigation systems. This IR&D made it possible for Honeywell to deliver to the Navy in 1966 the first operational Laser Gyro Triad system.

With a guidance and navigation market running well over a half billion dollars per year, the laser gyro opportunities are many and varied. The early contract applications have been oriented to high-g missile guidance, but virtually all guidance and navigation applications will be candidates in the future. In addition, the laser gyro is being considered for the heading reference system in torpedos, for the North Finder application and for missile-stabilization systems.

¹Honeywell Research Program 1964, Vol. I of IR&D, dated 15 April 1964, pp 148-150.

Honeywell Research Program 1965, Vol. I of IR&D, dated 15 April 1965, pp 157-166.

Honeywell Research Program 1966, Vol. I - Part 2 of IR&D, dated 1 September 1966, pp 25-35.

Honeywell Aeronautical Division Independent Development Program 1965, Vol. III - Part 1 of IR&D, dated 15 April 1965, p 2-359.

Honeywell Aeronautical Division Independent Development Program 1966, Vol. III - Part 1 of IR&D, dated 1 September 1966, p 164.

TITLE INFRARED (IR) DETECTORS

BRIEF DESCRIPTION: Honeywell detector projects have concentrated on perfecting infrared detectors with improved sensitivity and electrical properties as required for tactical and strategic military application. New materials and techniques have resulted in either very large detectors (.120" x .360") or very small (.003" x .003") sensitive area detectors in multiple element arrays. We are able to achieve precise area definition in these ultraminiature detectors, with separation of 0.0005 inch held on eight-element arrays. Work began in 1963 on these projects. The program is identified in the IR&D brochures as indicated in the notes below.¹ About \$600,000 has been spent to date (of which the Government has paid for \$440,000).

BENEFITS TO THE DOD RESULTING FROM EFFORT: Results have been so spectacular that concepts have moved from the research laboratory into actual field hardware within less than 18 months' time. End use of these detectors is classified, but it can be stated that the Honeywell-developed InSb sensors made possible the first usable IR mapping system in the southeast Asian theatre. Development by Honeywell of the HgCdTe detector has opened the 8- to 14-micron band for IR reconnaissance and facilitated the configuring of a new high-performance IR strip-mapper system. Matching the HgCdTe detector to a CO₂ laser illuminator holds promise for a breakthrough in active night-vision surveillance systems.

¹ Honeywell Aeronautical Division Independent Development Program 1964, Vol. III of IR&D, dated 15 April 1964, pp 2-212 to 2-217.

Honeywell Aeronautical Division Independent Development Program 1965, Vol. III - Part 1 of IR&D, dated 15 April 1965, pp 2-291 to 2-301.

Honeywell Aeronautical Division Independent Development Program 1966, Vol. III - Part 1 of IR&D, dated 1 September 1966, pp 167-169.

TITLE: SOLID STATE GAS PRESSURE TRANSDUCER

BRIEF DESCRIPTION: Over the past three years Honeywell has invested approximately \$175,000 of IR&D funds (of which the Government paid for about \$125,000) in the development of a solid state gas pressure transducer for use in advanced air data systems. In the IR&D brochure for 1966, this program is identified as Digital Solid State Pressure Transducer.¹

The electromechanical gas pressure transducer that has been used in current production air data systems is characterized by an assemblage of bellows, levers, cams, magnets, electronics, and other complexities which lead to problems in reliability and high cost. By contrast, the solid state gas pressure transducer design utilizes a single crystal silicon diaphragm, on which piezoresistive strain gauge elements have been diffused through micro-electronic processing techniques. Gas pressure applied across the diaphragm causes an unbalance in the strain gauge elements that is directly usable for electrical readout purposes. Although this readout can be in the form of analog voltages, the preferred readout method has a pair of strain gauge elements controlling the frequencies of a pair of oscillators in such a manner that the difference frequency is a measure of the gas pressure. The difference frequency can then be directly coupled to a digital computer to complete the advanced air data system. The single crystal silicon diaphragm, about the size of a five-cent piece, then effectively supplants the much more complex electromechanical design.

BENEFITS TO THE DOD RESULTING FROM EFFORT: The solid state gas pressure transducer is required to satisfy the more demanding air data requirements of the next generation of supersonic and hypersonic aircraft that could not be satisfied with the current production design air data system, which uses an electromechanical gas pressure transducer. These more demanding requirements include higher accuracy performance, a greater reliability, and lower cost.

¹Honeywell Aeronautical Division Independent Development Program 1966, Vol III - Part I of IR&D, dated 1 September 1966, p 177.



Page determined to be Unclassified
Reviewed Chief, RDD, WHS
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TEXAS INSTRUMENTS INCORPORATED

13500 NORTH CENTRAL EXPRESSWAY • DALLAS, TEXAS
APPARATUS DIVISION

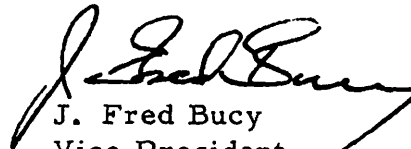
2 December 1966

Mr. E. B. Harwood
Office of the Director of Defense
Research and Engineering
Room 3D 1028
Pentagon
Washington, D. C. 20301

Dear Mr. Harwood:

In reply to Mr. Phillips' letter of November 4, I am enclosing brief resumes of research and development programs either in progress or recently completed by Texas Instruments Incorporated. I hope this information is sufficient. If you should need any additional data, I will be happy to supply it.

Sincerely,



J. Fred Bucy
Vice President

Enclosures

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Reviewed Chief, RDD, WHS
IAW EO 13526, Section 3.5
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EXAMPLES OF IR&D OF DIRECT BENEFIT TO DOD

Title: Silicon Transistor

Brief Description:

In 1952, based on 22 years' experience in the development and manufacture of electronic equipment, it was apparent to TI management that the small, rugged, low-power device, the transistor, would have significant impact on the future of electronics. Having obtained, in 1952, a license from Bell Telephone Laboratories to manufacture point-contact germanium transistors, a research team began work on the use of silicon to replace germanium to increase the power output and improve high-temperature performance.

The first working silicon transistor was developed by the research team in early 1954.

On May 8, 1954, TI announced the world's first mass production of silicon transistors, three years ahead of the time most scientists had predicted this could be accomplished.

Benefits to the DoD Resulting from the Effort:

The silicon transistor, for the first time, made transistors compatible with military use and environment. The use of this device in space vehicles, computers, avionics and myriad other applications revolutionized the electronics for these purposes. The reliability and size advantages made possible space programs that would not otherwise have been feasible. Large-volume, high-reliability computers for both ground and airborne application reached a new level of utility. Small, rugged equipments for field users were now possible and quickly came into being. In retrospect, it appears that this IR&D effort provided the DoD a device which quickly revolutionized the design of almost all electronic equipments in the military inventory to provide size, weight, cost and reliability improvements and that this effort produced the device at least three years ahead of the time it would otherwise have appeared.

Title: Semiconductor Integrated Circuit

Brief Description:

After development of the silicon transistor, Texas Instruments IR&D continued attempting to develop new forms and uses. This work was aimed at creating a semiconductor network which would integrate, on a single semiconductor wafer, both active elements (such as transistors) and passive elements (such as resistors and capacitors). In July 1959, the laboratory completed the first silicon semiconductor network. In March 1960, Texas Instruments announced the first commercial off-the-shelf availability of semiconductor networks, fully three years ahead of most industry predictions. They were complete networks, or circuits, containing both passive and active devices in densities at least 100 times greater than transistor circuitry.

Benefits to the DoD Resulting from the Effort:

The integrated circuit has caused another sweeping improvement in military electronics. It has removed another limiting barrier in size, in cost, in reliability and in complexity. Equipments are capable of being improved by at least an order of magnitude in each of these areas. Early DoD programs to be impacted by this IR&D were the Minuteman guidance system and the Apollo guidance computer, both initiated in 1962 and able to meet the cost, reliability and complexity goals only through the use of integrated circuits. Rapidly following these programs, integrated circuits have been applied to integrated avionics systems, advanced computers, communications equipment and space programs, in each instance providing step improvements in size, cost, reliability and capability to perform a task. New methods of providing capabilities have evolved with such revolutionary ideas as the development of throwaway communications equipment for military use, now in progress.

All of these steps were completed at least three years ahead of industry predictions, primarily owing to IR&D. The magnitude of this R&D effort by TI was estimated at \$10 million through 1963 by P. E. Haggerty.

Title: Helicopter Rotor Radar

Brief Description:

This is a joint effort between Texas Instruments and Bell Helicopter Company. The goal was the development of a radar system with the antenna integral to the helicopter's rotor blade, eliminating the increased bulk and scanning problems of conventional antennas and taking advantage of the extremely high resolution possible through the very small azimuth beamwidth. This equipment has successfully completed its flight-testing program, and an improved system is being proposed to the DoD.

Benefits to the DoD Resulting from the Effort:

Through the use of this very high-resolution, real-time-display radar system, the military will be able effectively to operate helicopters during the currently restrictive conditions of darkness and limited visibility. Information displayed by the system is of such high resolution that it may be used for target acquisition, navigation, approaches to remote areas under instrument conditions, and station keeping, and, with additional development, for terrain avoidance, terrain following and fire control. All of these uses are directly applicable to helicopter missions required in Vietnam, including troop transport, attack and rescue, and should provide not only increased mission effectiveness but also greater safety of operation. Additionally, the system provides a natural complement to other equipment planned for advanced helicopters such as the AH-1G Hueycobra and the Lockheed AAFSS.

Title: Terrain-Following/Terrain-Avoidance Radar

Brief Description:

In early 1958, TI began work on a radar system concept to enable aircraft to penetrate enemy defenses by flying under the radar net. To fly at the very low altitudes necessary for this approach at night or in poor visibility conditions, it is imperative that the aircraft have a means for following the ground contours and avoiding obstacles; this means is terrain-following radar. With these radar systems, the aircraft are able to maintain ground clearance of well under 1000 feet regardless of the contour of the terrain.

Benefits to the DoD Resulting from the Effort:

From TI research and development on terrain-following radar have come the APQ-99, APQ-110, APQ-115 and APQ-116 radar systems used on the RF-4B, RF-4C, F-111A, C-130 and A-7 aircraft for low-level penetration. The APQ-99 systems in the Phantom II aircraft are fully operational and are providing large increases in military reconnaissance capabilities.

Title: Infrared Developments

Brief Description:

For passive nighttime surveillance of enemy territory, infrared mapping systems have proven to be the most effective tools. Research and development efforts in this area have been directed toward development of new types of detectors, new concepts in optical systems and, most recently, development of a passive infrared night attack system.

Benefits to the DoD Resulting from the Effort:

Generally, the DoD has benefited through significant advances in the state of the art of battlefield and strategic reconnaissance and surveillance. Specifically, the work has led to the fully operational infrared systems (RS-7, RS-10, AAS-18, AAS-21 and others) used in the Phantom II and other reconnaissance aircraft. Forward-looking infrared systems are now demonstrating their capabilities for nighttime target detection and fire control.

Title: Helium Magnetometer — AN/ASQ-81

Brief Description:

As part of its ASW (antisubmarine-warfare) program, TI has been working since 1958 on development of magnetometers of greater range capability. The development of the metastable helium detector led to the ASQ-81 magnetic detection set which is capable of locating and identifying submarines at distances substantially greater than those possible with previous equipment. TI has been pursuing this program for over eight years and has been receiving development and production contracts from the U. S. Navy for approximately five years.

Benefits to the DoD Resulting from the Effort:

Through the use of this equipment, the Navy ASW forces are able to make positive identification of submerged submarines at distances greater than ever before. Also, the reliability is an order of magnitude better than that of existing systems owing to the use of all-solid-state components. The improved reliability substantially increases the probability of mission success and overall weapon-system effectiveness.

Title: Vela Program—Nuclear Testing Detection

Brief Description:

TI first entered Project Vela in 1959 when the technology used in prospecting for oil by seismic means was employed to detect and suggest the source of earth shocks generated by nuclear detonation. Since that time, these techniques have been vastly improved by the development of large-aperture seismic arrays, adaptive filtering methods and highly sophisticated means of electronic data processing. In addition, this program has led to the ocean-bottom seismic survey and to the technique of on-site inspection by gas analysis recently announced in Geneva.

Benefits to the DoD Resulting from the Effort:

This research program has brought major advances in the capability for detecting, identifying and locating nuclear explosions and other seismic disturbances, and, although not yet infallible, provides a very effective method of identifying nuclear blasts. The advanced signal-detection and data-handling techniques that have been developed in the Vela program have potential application to other military problems—seismic communication, ASW, early warning, etc. In addition, a great deal of basic knowledge about the earth and its structure has been gained. This knowledge is useful to the scientific community, to government and to industry.

Title: Seismic Intrusion-Detection (SID) Method

Brief Description:

This system, now in production, was developed as an evolutionary result of TI's work in seismology for oil exploration. The use of seismometers for intrusion detection stemmed from the large, undesirable signals produced by any human movement during oil-field seismic tests. The first military contract for six test models of these devices was received in 1963 from the U. S. Marine Corps and was followed by a contract for 21 evaluation models. In mid-1965, a contract for production quantities of the SIDs was received, and now approximately 2000 of the units are in service with the U. S. Army and Marine Corps and the British Army.

Benefits to the DoD Resulting from the Effort:

The development of this equipment enables the military ground forces to establish a perimeter that a human cannot in any known manner sneak past, even in dense jungle areas such as there are in Southeast Asia where radar and infrared systems are blocked by the dense foliage.

Title: Gallium-Arsenide Infrared Light Emitters and Optoelectronic
Devices

Brief Description:

This program was begun in 1961 to develop an infrared light source that is small, bright and capable of modulation for optoelectronic applications. The program resulted in the first commercially available gallium-arsenide light emitter in 1962 and the first commercially available high-power light emitter in 1963. These product developments have now been expanded into a line of 14 visible and infrared solid-state light emitters currently available from TI.

Benefits to the DoD Resulting from the Effort:

The development of these devices represents an advancement in technology resulting in the development of systems that were previously infeasible and in improvements for other systems. Potential applications of these devices are in terrain-illumination equipment for tactical surveillance; very small covert infrared communications systems; high-speed, multichannel film recording; light emitters for more reliable, higher speed computer card readers; and advanced optoelectronic circuit functions resulting in reduced weight in airborne optoelectronic equipment.

Title: Gunn Effect Devices

Brief Description:

Research on the Gunn effect was begun at TI in early 1965 and is continuing. Work is now under way to develop an oscillator, multiplier and mixer on one semiconductor chip using this principle, to be employed in a 94-gigacycle, millimeter-wavelength, integrated receiver. The goals of this program are to develop such a Gunn-effect oscillator or an avalanche diode to replace low-power klystron tubes and ultimately to develop a fully integrated, lightweight microwave system, since with this device it will be practical to use power supplies of less than 100 volts, possibly batteries or even solar cells.

Benefits to the DoD Resulting from the Effort:

The DoD will benefit directly from the development of these devices through major improvements in man-carried radar systems for battlefield surveillance such as are needed in Vietnam, in simplifying phased-array radar systems, in airborne automatic collision-avoidance systems especially necessary for high-performance aircraft operating in marginal weather conditions as prevail in Southeast Asia, in throw-away signal-jamming equipment that may be dropped either on a battlefield or near an enemy electronics installation, and also in spaceborne long-life microwave communications systems.

SYLVANIA ELECTRIC PRODUCTS INC.

SUBSIDIARY OF

GENERAL TELEPHONE & ELECTRONICS CORPORATION

40 SYLVAN ROAD, WALTHAM, MASS. 02154

DR. LEONARD S. SHEINGOLD
VICE PRESIDENT
ADVANCED TECHNOLOGY
SYLVANIA ELECTRONIC SYSTEMS

Page determined to be Unclassified
Reviewed Chief, RDD, WHS
IAW EO 13526, Section 3.5
Date: MAR 08 2011

30 November 1966

Mr. E. B. Harwood
Office of the Director of Defense
Research and Engineering
Room 3D1028, The Pentagon
Washington, D.C. 20301

Dear Mr. Harwood:

Attached are a few examples of Sylvania's Independent Research and Development (IR&D) projects which have resulted, or may result, in programs of direct benefit to the Department of Defense.

I have attempted to be responsive to your request of 4 November 1966 and perhaps could have cited additional specific examples. However, I would like to stress that we consider the indirect benefits to be of equal importance.

IR&D permits us to conduct a cohesive technical program and to support advanced technology projects which provide continuity of effort for our technical staff members. Naturally, we attempt to relate our IR&D Program to contractual support and known government requirements. Upon several occasions, however, we have used the IR&D Program to generate a new requirement (e.g., Morse Code Trainer).

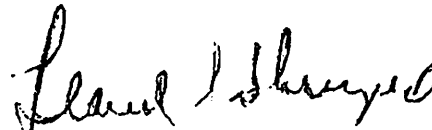
We attempt to avoid large individual projects by committing ourselves to a system concept, identifying the critical element of the system, and by concentrating our IR&D effort on only the critical portion of an advanced system (e.g., Solenoid Array Correlator).

A good percentage of our IR&D effort is devoted to new-techniques projects in electronics. Quite

frequently, the military services will award "pump priming" contracts to a company or two with a view toward a sharp upgrading of the over-all state-of-the-art. The entire field of microelectronics was created by this type of support. Only through the IR&D Program could we mount a rapid effort to be responsive to RFQ's and also be competitive (e.g., Thick-Film Microelectronics Technology).

I hope that the enclosed information will be useful to you in its present form. Please let me know if you need additional material.

Sincerely,



Leonard S. Sheingold

Encls.

TITLE: SOLENOID ARRAY CORRELATOR

Page determined to be Unclassified
Reviewed Chief, RDD, WHS
IAW EO 13526, Section 3.5
Date: MAR 08 2011

Brochure Reference:

1963 - A.3.2, A.3.5

1964 - A.3.2.1, A.3.2.4

Estimated Dollar Expenditures:

Government: \$45,000

Company : 15,000

TOTAL \$60,000

Brief Description:

The Solenoid Array Correlator is one of a family of solenoid array devices that resulted from research in pattern-recognition systems. The device itself consists of an array of long, thin cylindrical solenoids into which the data to be analyzed or correlated is introduced. These solenoids, though a simple layer of wire on a plastic rod, have a very uniform magnetic field which is selectively sensed by equally simple and component-free printed circuit sheets. These sheets are made of thin mylar film clad with copper. Since these sheets are very thin, a sandwich of a thousand sheets is only a few inches thick. The solenoids pass through holes in the sheets, and the path or loops of the copper conductor on each sheet store all the data for each stored correlation pattern. The interaction of the solenoid and loops on the sheet result in an accurate matching or correlation between the input which is to be analyzed and all the stored data in the array in a few millionths of a second. Each bit to be correlated drives a solenoid, and each correlation plane simultaneously makes a vector summation of the coupled loops on the sheet to indicate degree of correlation.

Significance

The significance of this technique is its ability to match an unknown with a large number of stored known patterns of a signal (more than 1000) and obtain an indication of best fit in a few

microseconds. In this application, this small device is capable of exceeding the capability of a very large computer or a huge complex array of special-purpose filters. This makes possible the realization of a highly selective weapons system with a simple data processor which can easily operate under the most severe equipment environment.

Benefits to DOD:

The Solenoid Array Correlator is being evaluated in a torpedo signal processor. In this application it is superior to other approaches because of its extremely high-speed processing capability, large-capacity non-destructive memory, reliability, and small size. This advance in technology will allow sophisticated signal processing to be carried out in the limited space of a torpedo and thereby improve the effectiveness of the weapons system.

TITLE: MILLIMETER COMMUNICATIONS

Brochure References:

1964 - B.2.2.10
1965 - B.2.2.3 - B.2.2.4
1966 - B.3.7

Estimated Expenditures:

| | |
|----------------|---------------|
| Government | \$75,000 |
| Company Profit | <u>25,000</u> |
| TOTAL | \$100,000 |

Brief Description:

An all-solid-state voice transceiver operating at millimeter wavelengths was constructed and tested on a short overland link. The transmitter and receiver were crystal controlled to one part in 10^7 for narrow-band operation and eliminated the previous high-voltage power supplies by substituting harmonic generators for tube oscillators.

Significance:

The significance lies in demonstrating that communication in the millimeter region is feasible, practical and cost effective for many specialized military applications. Among the specific applications are those requiring: 1) low detectability through narrow beamwidth, atmospheric signal absorption, or low side-lobe levels; 2) small-size, high-gain antennas; 3) alleviation of spectrum crowding; 4) an extra measure of protection from jamming; 5) penetration through fog; and 6) the availability of sufficient bandwidth for high-rate transmission. Whereas most of these characteristics were predicted to be theoretically possible many years ago, our efforts have demonstrated feasibility through development of solid-state hardware.

Benefits to DOD

Our millimeter IR&D has produced technological advances which have been put into the TR-601 transceiver. This unit is a 15 N.M. range line-of-sight voice system of entirely solid-state construction; no tubes are utilized. Before this equipment was developed, short-haul requirements could only be met by bulky and short-lived power-output tubes, high-voltage power supplies and complicated frequency stabilization equipment. The development of the TR-601 brought to the millimeter region the characteristics of long-life semiconductor reliability, low-voltage operation and total-system size reduction. The need for such characteristics was initially identified on an early contractual Navy program, but it was left for our IR&D to produce the necessary feasibility development. Sylvania participated in several field demonstrations and operational tests in geographical areas, including Washington, D.C., and southern California. These graphically demonstrated the practicability of compact and economical millimeter sets for ship-ship, ship-shore, and overland fixed-mobile communications. These tests included the first proof that it is possible to use narrow-beam millimeter or microwave transmissions on ships underway at sea.

A not-too-well-recognized, but nevertheless important side benefit of millimeter developments is the technology advancement which accrues to lower frequency bands. For example, in translating to an EHF output, a solid-state millimeter set typically uses amplifier and multiplier circuits at HF, VHF, UHF and SHF bands. The stringent demands on producing the requisite power level, spectral purity and bandwidth at the output create refinements necessary to efficient and reliable operation of lower frequency stages.

TITLE: MORSE CODE TRAINER

Brochure Reference:

1963 - A.3.2
1964 - A.3.2.1
1965 - A.3.4

Estimated Expenditures:

Government: \$45,000
Company : 15,000
TOTAL \$60,000

Brief Description:

The system is basically a computer-aided, audio-visual trainer. It employs adaptive selection of stimulus material based on the individual student's performance, continuous and highly specific reinforcement, and both self and adaptive pacing to teach typing and Morse Code receiving more rapidly than conventional methods.

Significance:

The major significance of the effort, in addition to the cost savings discussed below, lies in the fact that this system embodies a unique combination of psychological principles of learning never before combined in a training system.

Benefits to DOD:

In 1965 a two-position system for Morse Code receiving was designed, constructed, and tested. Evaluations were made using students from the Army training facility at Ft. Devens. As a result of this evaluation a 24-position system is presently being procured by Ft. Devens for larger scale operational evaluation.

A cost-effectiveness analysis was performed that indicates that a 3% reduction in training time will result in a break-even position. Predicted reductions in training time vary from a minimum of 15% to as much as 30%.

With a 15% reduction in training time, an annual cost reduction of \$3500 per position is projected. With more than 3000 Morse Code training positions now being operated by the three services, many on a two or three-shift basis, annual one-shift savings would reach \$10,500,000.

TITLE: THICK-FILM MICROELECTRONICS TECHNOLOGY

Brochure References:

1964 - B.2.3.1
1965 - B.2.4.4
1966 - B.4.4

Estimated Dollar Expenditures:

| | | |
|------------|---|----------------|
| Government | - | \$394,000 |
| Company | | <u>131,000</u> |
| TOTAL | | \$525,000 |

Brief Description:

Thick-film microelectronics technology involves the use of relatively thick multilayer-deposited films to replace conventional wiring and, in some cases, discrete components.

Significance:

The use of multilayer thick films as a substitute for wiring and printed-circuit boards offers many engineering and performance advantages, including reduced size, higher packing densities, improved reliability, and better mechanical ruggedness.

When the advantages of thick-film technology are coupled with advantages of solid-state components and microcircuits, truly dramatic reductions in overall equipment size and power requirements can be achieved.

Benefits to DOD

Based on a known military requirement, Sylvania developed an improved military rescue radio transceiver/beacon which has been assigned the nomenclature PRC-63. This radio set utilizes thick-film techniques, together with solid-state devices, to achieve a volume of approximately one-third, and a weight of one-quarter, of existing equipment at the same unit production cost. Reduced power drain results in battery-replacement costs' being reduced by a factor of six.

The set developed has already been procured in small lots by the Navy, Army, and Air Force, and large full-scale production is anticipated.

The availability of the PRC-63, with its improved reliability and performance to meet the current need for radio rescue equipment, can be directly attributed to Sylvania's independent development program.

TITLE: INTERCEPT RECEIVERS

Page determined to be Unclassified
Reviewed Chief, RDD, WHS
IAW EO 13526, Section 3.5
Date: MAR 08 2011

Brochure References:

| | |
|--|--------|
| 1965 - Receiver Development Techniques | B-115 |
| 1966 - Receiver Techniques Study | B.5.8 |
| K-Band Sweeping Receiver | B.5.2. |
| Solid State LO For R-31 | B.5.3 |

Estimated Dollar Expenditures:

| | |
|------------|---------------|
| Government | \$183,000 |
| Company | <u>62,000</u> |
| TOTAL | \$245,000 |

Breif Description:

Intercept receivers, covering the range of 2 Hz to 40 GHz, voltage-tuned from 40 Hz to 40 GHz.

Significance:

The capability to electronically tune a receiver provides greater versatility in intercept applications since the frequencies can be selected more rapidly than by manual tuning. The technique also adapts itself to remote operation of several receivers by a single operator.

Benefits to DOD

These receivers are now installed in operational surveillance systems, as fixed-station, airborne, and surface-vessel installations in many parts of the world. The performance of these receivers, which represents a definite advance in technology, enables the collection of valuable electronic signal data under severe signal environments which would be irretrievably lost to prior model receivers.

The development of these receivers under Sylvania's Independent Development Program has enabled quick reaction to the requirements of electronic warfare systems on an expedited time basis with off-the-shelf advanced-state-of-the-art receivers with maximum useful life.

TITLE: AVIONICS RECEIVER, TRANSMITTER AND TRANSCEIVER TECHNIQUES

Brochure Reference

1963 - B.2.2.2, B.2.2.3, B.2.2.4
1964 - B.2.2.2, B.2.2.3, B.2.2.4, B.2.2.9
1965 - B.2.2.2, B.2.2.3, B.2.2.4, B.2.2.5
1966 - B.3.4, B.3.5, B.3.6, B.3.7

Estimated Dollar Expenditures:

| | |
|-------------|---------------|
| Government: | \$144,000 |
| Company | <u>48,000</u> |
| TOTAL | \$192,000 |

Brief Description:

Exploitation of rapidly evolving solid-state technology in the development of receivers, transmitters and transceivers to provide dramatic improvements in tactical communications equipment.

Significance:

A major hindrance in the past to providing tactical communications down to the lower echelons where it was needed, has been in obtaining equipment sufficiently small, rugged and reliable.

Beginning in 1963, in recognition of the importance of rapid advances in transistor technology, Sylvania undertook a series of related efforts in transmitter and receiver design aimed at fully exploiting these advances to achieve small, highly reliable tactical radio equipment. Several related programs have been carried on continuously since that time. These have included development of fully solid-state transmitters for frequencies through the UHF band, a solid-state broad-band frequency synthesizer for these bands, and exploitation of application of microelectronics packaging techniques.

The development of solid-state transmitter units capable of generating the power levels necessary for tactical radio communications has made it possible to fully replace vacuum tubes in such equipment,

resulting in major improvements in ruggedness and reliability. At the same time, continual exploitation of transistor circuitry and, more recently, exploitation of the more compact integrated circuit components have made it possible to develop major functions in truly portable units for man-pack use. They have also made it possible, as in the case of the Light Observation Helicopter Avionic package now under development by Sylvania, to cram into an incredibly small space all the communications functions necessary to make such aircraft fully effective in the battlefield environment.

The importance of taking maximum advantage of emerging solid-state technology as rapidly as it becomes available from component manufacturers is that not only can one make equipment smaller, but actually it becomes more reliable and less costly to produce.

Benefits to DOD:

The techniques have been applied directly to the major components of the LOH Avionics package; namely, the ARL-114, ARL-115, and ARL-116 transceivers. In addition to small size and high reliability, these units have full channel capability without the problems of mechanical switching assemblies. With this added channel capability, the many components of field units can communicate without interference from friendly equipment and have maximum feasibility to avoid unfriendly jammers.

Page determined to be Unclassified
Reviewed Chief. RDD, WHS
IAW EO 13526, Section 3.5
Date: MAR 08 2011

MOTOROLA INC.



Military Electronics Division / Western Center

November 25, 1966

Page determined to be Unclassified

Reviewed Chief, RDD, WHS

AW EO 13526, Section 3.5

Date: **MAR 08 2011**

Office of the Director
Defense Research and Engineering
Room 3D 1028
Pentagon
Washington, D.C. 20301

Attention: Mr. E. B. Harwood

Dear Mr. Harwood:

In response to Mr. Phillips' letter of November 10 to Dr. Daniel E. Noble, we are pleased to tender the attached specific examples from our IR&D program.

These include some examples of Independent Development Projects from the Aerospace Center of our Government Electronics Division. We also include examples of projects from the Chicago Center of our division; however, some of this latter information was delayed in reaching us, and will be forwarded as soon as received.

Since our division of Motorola is entirely devoted to development and manufacturing of electronics apparatus for the Government, our IR&D program is completely oriented towards present and future Government requirements as we see them. Our management is enthusiastic about the mutual benefits that have resulted and will continue to do so.

As a result of the program, we feel that we are in much better position to offer realistic state-of-the-art solutions to your stated requirements. From your standpoint, this should mean a higher confidence that you will actually receive equipment with the performance and reliability you have requested, with considerably reduced expectation of contract overruns and delays. In some cases, we have noted instances where we have bid and lost (for example, IHAS radar); we contend that this has worked to your benefit by supplying strong competition with resulting lower cost to you.

Although you request DOD examples, we have included several with primary payoffs shown as being to NASA. These are important to you for several reasons. First, much of the technology, will be directly applied to the military space effort, in which we

are beginning to participate heavily (SGLS, for one example). Second, the space work has developed technologies for order-of-magnitude improvement in reliability of apparatus; and since we have a close-knit engineering organization, we actually spread this knowledge into our military projects for use.

We will be glad to submit more information, either in writing or in person. It may be of interest to you that we will have a review of our IR&D program by a Tri-Service committee headed by Dr. Joseph Kaufman on December 5, 6, and 7; you may wish to communicate with them as well.

Yours very truly,



R. E. Samuelson
Director of
Research and Development

cc: D. E. Noble
J. P. Jones
J. A. Chambers/J. F. Byrne

Examples attached:

General Purpose Radars
Proximity Fuzing Radars
S-Band Solid-State Telemetry Transmitters
Standard RF Circuit Development
Integrated Circuit Interconnect Study
Microwave Devices
Bulk Effect (Electroacoustic) Devices
Telemetry Voltage-Controlled Oscillators
TP-4000 High Speed Teleprinter*
Delta Digital Multiplex*
MP-7 Portable Microwave*
Integrated Electronic Frequency Synthesizer*

*Chicago Center Projects - partial information

EXAMPLES OF IR&D OF DIRECT BENEFIT TO THE GOVERNMENT

TITLE: General-Purpose Radars (including Terrain-Following)

| | | | | | |
|---------------------------|---------------|---------------|---------------|---------------|---------------|
| IDP's: | <u>7616</u> | <u>7620</u> | <u>7626</u> | <u>7633</u> | <u>7638</u> |
| 1964-1965 Brochure: pages | <u>235</u> | <u>237</u> | <u>239</u> | - | - |
| 1965-1966 Brochure: pages | - | - | - | WC-92 | WC-94 |
| IDP's: | <u>7647</u> | <u>7649</u> | <u>7651</u> | <u>7657</u> | <u>7658</u> |
| 1965-1966 Brochure: pages | <u>WC-102</u> | <u>WC-106</u> | <u>WC-108</u> | <u>WC-112</u> | <u>WC-114</u> |
| IDP's: | <u>7683</u> | <u>7684</u> | <u>7660</u> | <u>7663</u> | <u>7664</u> |
| 1965-1966 Brochure: pages | <u>WC-118</u> | <u>WC-104</u> | <u>WC-116</u> | - | - |

DESCRIPTION:

Time Period: September 1963 to date Cost to Date: \$462,201
(over-all)

Beginning with a modest effort to investigate the possibilities of an improved key element of a radar system (a range-gated processor), the study was expanded to demonstrate and evaluate a complete radar system exploiting this technique. Development work on the high-speed phase scanners and on the electronically scanned antennas for aircraft followed. Beginning in January of 1965, a complete demonstration flight system was undertaken, and flight tests followed in 1966. Currently, difficulties encountered during test are being evaluated and new solutions incorporated in the equipment to permit completion of the flight tests.

BENEFITS TO THE GOVERNMENT:

Although not yet completed, this program of related IDP's has already contributed significantly toward an improved competitive bidding situation for the government. Based on intermediate results and on skills gained from these IDP's, Motorola has provided competitive technical proposals on the following RFQ's:

| <u>Title (Aircraft)</u> | <u>Customers</u> |
|-------------------------|---------------------------------------|
| AAFSS | Lockheed, Teledyne |
| B-52 | IJM-Boeing |
| C5A | Boeing |
| IHAS | Teledyne |
| MK II | General Dynamics |
| OV-10A(COIN) | North American |
| US/FRG | Boeing, Lockheed, McDonnell, Republic |

TITLE: Proximity Fuzing Radars

IDP's: 7655 7687 7688
1965-1966 Brochure. page WC-110 - -

DESCRIPTION:

Time Period: May 1965 to present Cost: \$44,095

A study in correlation radar techniques was followed by development and evaluation of a suitable seeker antenna/radome assembly. A third IDP combined these two inputs into study and breadboarding for application to small missiles. The results of these IDP's were most timely for use in preparing successful proposals on critical immediate applications.

BENEFITS TO THE GOVERNMENT:

It would be impossible to meet the delivery demands of current proximity-fuze requirements to support our troops if the R and D phases had not already been accomplished. Preparedness in basic designs has permitted Motorola to commit materials and production tooling at once, to be accomplished in parallel with the final package design and prototype testing. Early deliveries and high production rates, made possible by these IDP projects, are under way on the following contracts:

| <u>Motorola Project</u> | <u>Title</u> | <u>Agency</u> | <u>Contract</u> |
|-------------------------|------------------------------|---------------|------------------|
| 3146, 5147 | FMU-56/B Service Test Models | WPAFB | AF08(635)-5411 |
| 3264 | Early production tooling | WPAFB | AF08(635)-5411 |
| 5148, 5149 | Early production | WPAFB | AF08(635)-5411 |
| 3333 | Main production program | WPAFB | F33657-67-C-0696 |
| 3334 | Main production facilities | WPAFB | Pending |

TITLE: S-Band, Solid-State Telemetry Transmitters

| | | | | | |
|---------------------------|--|-------------|-------------|-------------|-------------|
| IDP's: | | <u>7608</u> | <u>7637</u> | <u>7644</u> | <u>7666</u> |
| 1964-1965 Brochure: pages | | <u>185</u> | <u>193</u> | - | - |
| 1965-1966 Brochure: pages | | - | WC-18 | WC-60 | WC-38 |

DESCRIPTION:

Time Period: May 1963 to September 1966 Total Costs: \$194,435
(over-all)

Studies of overall telemetry transmitter requirements and alternate approaches were combined with the development of high-power, solid-state signal sources. Extensive performance tests were then run on the resulting engineering model of a high-power, solid-state, FM telemetry transmitter. Continuing work on increasing the RF power output and improving efficiency has formed the basis for several successful technical proposals.

BENEFITS TO THE GOVERNMENT:

The R&D lead time before contract award of the below-referenced contracts was about three years. With the fundamental designs already accomplished under IDP projects, it was necessary for the government agencies to pay only for the requirements unique to each application. Program lead times were shortened by many months. Design maturity and reliability are greatly enhanced.

The following specific contracts are utilizing the techniques developed under the above IDP's:

| <u>Motorola Project</u> | <u>Title</u> | <u>Agency</u> | <u>Contract</u> |
|-------------------------|------------------------------|---------------|------------------|
| 3236 | IRLS Telemetry Transmitter | Goddard | NAS5-10195 |
| 3248 | Nimbus Telemetry Transmitter | Goddard | NAS5-10258 |
| 3257 | CTLI Telemetry Transmitter | Boeing | C- C-703262-7691 |
| 3287-1 | Poseidon Transmitter | Lockhead | BLX-758570 |

TITLE: Standard RF Circuit Development

IDP's: 7665
1965-1966 Brochure: page WC-22

DESCRIPTION:

Time Period: November 1965 to June 1966 Cost: \$43,911

Techniques originally developed for welding and potting digital cordwood modules were extended into the radio-frequency region. Six standard RF modules were developed which now have wide application in aerospace ground equipment. Circuit designs are such that modules may be directly interconnected. A novel plated - plastic feature provides excellent RFI shielding.

BENEFITS TO THE GOVERNMENT:

Success with the standard RF modules developed under this project has enabled Motorola to build modules for stock in anticipation of future government requirements. This approach enables Motorola to meet tight schedule requirements typically associated with government space programs. Elimination of re-engineering costs results in major cost savings. A recent study indicated that the standard RF module approach will save the government \$50,000 in a forthcoming program for SGLS Receivers.

Standard RF modules have been used in the following programs:

| <u>Motorola Project</u> | <u>Title</u> | <u>Agency</u> | <u>Contract</u> |
|-----------------------------|---|---------------|-----------------|
| 3022 | Meteorological Vertical Sounding System | AFCRL | AF19(628)-4215 |
| 3172 | Command and Communication System Tests Sets | NASA/MSC | NAS 8-20546 |
| 3226 | S-Band Transponder Labora- tory Test Equipment | NASA/MSC | NAS 9-5939 |
| 3276 | SGLS Receiver | Philco | Letter contract |

TITLE: Integrated Circuit Interconnect Study

IDP's: 7617
1964-1965 Brochure: page 305

DESCRIPTION:

Time Period: August 1963 to June 1964

Cost: \$25,759

The "flat-pack" type integrated circuit has presented severe problems relative to interconnecting the closely spaced leads. An imaginative solution to this problem has resulted from the subject IDP. Featuring kovar-clad mylar interconnect patterns joined by resistance welding, the "micro-harness" module includes up to 20 flat-pack integrated circuits in a high-density configuration compatible with the digital cordwood module developed under another IDP.

BENEFITS TO THE GOVERNMENT:

The organized, systematic approach provided by "micro-harness" enables technicians and draftsmen to package electronic equipment, thus freeing up critically needed engineering specialists for more important assignments. At the same time "micro-harness" permits achievement of smaller and lighter high-reliability electronic assemblies than achievable with previous technologies. The above factors played an important part in NASA's decision to award the Mariner '69 spacecraft computer to Motorola.

The micro-harness technology developed under this IDP has been applied to the following programs:

| <u>Motorola Project</u> | <u>Title</u> | <u>Agency</u> | <u>Contract</u> |
|-----------------------------|-------------------------------------|---------------|---------------------------------|
| 3167 | Intergrated Circuit Up-Data-Link | NASA/MSC | NAS 9-5366 |
| 3065 | AROD | NASA/MSFC | NAS 8-11835 |
| 3279 | Central Computer and Sequencer | NASA/JPL | NAS 5-700 |
| | SGLS TT&C | Lockheed | (Proposed under Program 770) |

TITLE: Microwave Devices; Diode Switches:

IDP's: 7632 7669
1965-1966 Brochure: page WC-224 WC-236

DESCRIPTION:

Time Period: June 1965 to April 1967 Eventual Cost: \$56,477
(planned)

Preliminary work on the application of diodes as switches was directed at evaluation of devices and development of circuit functions. The second step was the development of specific applications using switching and limiting. By combination of diode switches with lengths of transmission lines, programmable phasing can be accomplished.

BENEFITS TO THE GOVERNMENT:

The phasing applications are applicable to electronically steered antennas which are needed in a variety of airborne and ground-based systems. Switching and limiting are used extensively in radar and fuzing applications. The basic techniques developed under these IDP's have permitted high-confidence bidding on the following programs with improved delivery and reduced total cost:

| <u>Motorola Project</u> | <u>Title</u> | <u>Agency</u> | <u>Contract</u> |
|-----------------------------|------------------------------------|---------------------|-----------------|
| 3146 | FMU-56/B Fuse | Eglin AFB | AF08(635)-5411 |
| 3173 | (Secret:) Broadband Development | General Dynamics | 139634 |
| 3176 | Electronic Goniometer Technique | RADC | AF30(602)-3960 |
| 3247 | Switch Scanning Antenna, ECM | WPAFB | AF33(615)-5018 |

TITLE: Bulk Effect (Electroacoustic) Microwave Devices

IDP's: 7672
(New since brochure)

DESCRIPTION:

Concurrently with literature studies, and based on previous similar work, sample electroacoustic elements were fabricated to explore their characteristics, parameters, and potential. Based on promising possible applications, the facilities and skills were expanded to develop new techniques more nearly meeting the device requirements. Attention was then turned to the use of the bulk-effect elements in specific designs of electroacoustic microwave amplifiers and delay lines. This phase is being followed by development of complete circuits. Meanwhile, devices are being fabricated for use in product-development projects.

BENEFITS TO THE GOVERNMENT:

This effort has resulted in the creation of a new capability and small-scale fabrication facility in a new technological area of electronics. Part of the effort is producing electroacoustic delay lines having a very small fraction of the cost, size and weight of their conventional counterparts for fuzing radars now being developed under another IDP. Simultaneously, the government is enjoying the benefits of a new technical capability for the following advanced development project of military significance:

| <u>Motorola Project</u> | <u>Title</u> | <u>Agency</u> | <u>Contract</u> |
|-----------------------------|---|---------------|-----------------|
| 3233 | Feasibility of Electro- acoustic Transceiver (FEAT) | RADC | AF30(602)-4251 |

TITLE: Telemetry Voltage - Controlled Oscillators

IDP's: 7628
1964-1965 Brochure: page 191
1965-1966 Brochure: page WC-16

DESCRIPTION:

Time Period: June 1964 to February 1965 Cost: \$5,551

Early space programs at Motorola suffered for lack of suppliers of reliable voltage-controlled oscillators (VCO's). The Motorola-developed command receiver for the Gemini-Agena target vehicle, for example, was in jeopardy at one time for this reason. Under IDP 7628, a VCO was developed that exceeds IRIG specifications by a significant margin over wide temperature ranges. The Motorola design is backed up by an exhaustive computer analysis performed under the IDP. In one configuration, a novel active filter obviates the need for bulky inductive devices, thereby reducing weight and size.

BENEFITS TO THE GOVERNMENT:

Voltage-controlled oscillators are generally used in telemetry systems and are typically the longest lead-time item in the program. The proven VCO design developed under this IDP permits Motorola to support NASA and DOD programs on a quick-reaction basis, thus preventing costly schedule delays. The high stability and linearity of these VCO's enable collection of high-accuracy data on national missile and space programs.

The subject VCO design is being employed in the following programs:

| <u>Motorola Project</u> | <u>Title</u> | <u>Agency</u> | <u>Contract</u> |
|-------------------------|-----------------------------|---------------|-----------------|
| 3145/3191 | Surveyor VCO's | Hughes | 04-403122-F39 |
| 3151 | Apollo VCO's | Collins | C-925060 |
| 3282 | CTLI Oscillator Subassembly | Boeing | C-708581-7691 |

TITLE: TP-4000 High-Speed Teleprinter

| | | | | | |
|---------------------|------|---------------|---------------|---------------|---------------|
| IDP's: | | <u>7704</u> | <u>7723</u> | <u>7743</u> | <u>7746</u> |
| 1965-1966 Brochure: | page | <u>CC-138</u> | <u>CC-144</u> | <u>CC-146</u> | <u>CC-148</u> |
| IDP's: | | <u>7770</u> | <u>7774</u> | <u>7776</u> | <u>7787</u> |
| 1966-1967 Brochure: | page | <u>4.2-1</u> | <u>4.2-2</u> | <u>4.2-3</u> | <u>4.2-4</u> |

DESCRIPTION:

Time Period: Early 1963 to present Cost to Date: \$174,832

Following development and refinement, Motorola has supplied to NASA (through UNIVAC) nine complete teleprinter systems for use at Apollo Tracking Stations as part of the message-switching system.

TITLE: Delta Digital Multiplex

| | |
|---------------------|--------------------|
| IDP's: | <u>7736</u> |
| 1965-1966 Brochure: | page <u>CC-112</u> |

DESCRIPTION:

Time Period: October 1964 to June 1965 Cost: \$44,114

Twenty-four-channel digital multiplex equipment has provided the Air Force a new, effective technique for overcoming path anomalies in marginal tropo systems. The IDP equipment has been tested under contract with the Air Force over the AMR (Atlantic Missile Range) link from Grand Turk Isle to San Juan, Puerto Rico. Additional AF tests over additional links are planned.

In addition, the award to Motorola for the development of the Lightweight Tactical Tropo is a result, to a very large extent, of an outstanding performance record in the AMR tests.

TITLE: MP-7 Portable Microwave

IDP's: 7578/7712
1964-1965 Brochure: page 51

DESCRIPTION:

Time Period: November 1962 to September 1964 Cost: \$107,344

MP-7 Portable Microwave - The MP-7 is a two-way portable wide-band microwave communications set, the feasibility of which was established on an IDP project. This equipment is currently used on the Edwards A.F.B. Test Range as a significant component of the "Microwave Data Acquisition and Transmission System" between Edwards A.F.B. and Vandenburg A.F.B.

TITLE: Integrated Electronics Frequency Synthesizer

| | | | |
|--------------------------|------|------|-------|
| IDP's: | 7719 | 7731 | 7755 |
| 1965-1966 Brochure: page | - | - | CC-58 |
| 1964-1965 Brochure: page | 15 | 23 | - |

DESCRIPTION:

Time Period: April 1965 to October 1965 Cost: \$106,724

The techniques developed on this IDP project are finding a wide variety of applications in meeting government requirements for stable, compact, tuneable frequency sources. One recent direct application of this project is on the ILAAS program. The Chicago Center is currently developing for Emerson Electric (ILAAS - contractor for on-board CNI checkout system) source for the on-board CNI self-test, one-checkout system on the A7A/B aircraft.

Office of Vice President

United Aircraft

December 6, 1966

Page determined to be Unclassified
Reviewed Chief, RDD, WHS
IAW EO 13526, Section 3.5
Date: MAR 08 2011

Office of the Director of Defense & Engineering
Attention: Mr. E. B. Harwood
Room 3D 1028, Pentagon
Washington, D. C. 20301

Dear Mr. Harwood:

In response to the request of Mr. Thomas L. Phillips of the Defense Science Board, the attached examples of IR&D effort which have resulted in significant benefit to the DOD are submitted.

I feel that a great deal of the value of this work and the low cost of the activities involved stem from the current policy of loosely monitoring such endeavor. Had it been necessary to thoroughly justify these highly successful programs at the inception of each, they would probably never have come into being. Moreover, had we to follow all of the procedures characterizing established specific DOD programs, the cost would have been many times that reported here. Through the IR&D programs, the DOD allows a relatively free rein on the imagination and innovative ability of industry, an asset of great value.

Very truly yours,



P. W. Pratt

Vice President and Chief Scientist

Enclosures

EAST HARTFORD, CONNECTICUT 06108

Page determined to be Unclassified
Reviewed Chief, RDD, WHS
IAW EO 13526, Section 3.5
Date: MAR 08 2011

EXAMPLES OF IR&D OF DIRECT BENEFIT TO DOD

TITLE: Absorbing Devices for Suppression of Rocket Combustion
Instability

DESCRIPTION:

In 1963, several uncooled absorbing liners were fabricated and tested to determine if acoustic liners could be used in rocket combustion chambers to suppress combustion instability. The liners were found to be effective; therefore, in 1964 a convectively cooled liner was fabricated and tested to demonstrate the practicality of the devices. The program led to the development of a workable solution to the problem of rocket engine combustion instability.

IR&D Brochure Identification: FP 64-82 (1965)
FP 65-121 (1966)

BENEFITS TO THE DOD RESULTING FROM THE EFFORT:

Pressure oscillations caused by unstable burning in rocket combustion chambers are a serious problem. The pressure oscillations can themselves destroy the engine, or may cause heat transfer rates above the cooling capability of the engine, resulting in engine destruction. The phenomenon is a resonant acoustical vibration reinforced by energy released in the combustion process. Basic studies to develop a general theory explaining the cause of combustion instability have been unsuccessful.

Until the last few years, the use of injector baffles has been the most widely used—but not completely successful—method of suppressing combustion oscillations in rocket engines. Since the baffle configurations must be developed empirically, large expenditures of funds and development time are needed. In addition, it is necessary to design injectors to conform to the configuration of the injector baffles, usually at the expense of combustion efficiency.

The use of absorbing liners in rocket motors is one of the most important contributions to liquid rocket combustion technology to date. Direct benefits to the DOD include both money and time savings since an absorbing liner can be included in the original design of the combustion chamber and the design of the injector need not be compromised in an attempt to achieve stability.

The American Society of Aeronautics & Astronautics has recognized the significance of this work by awarding the Goddard Medal to George D. Lewis and Wade Blackman, the United Aircraft Corporation engineers responsible for this work.

TITLE: High-Pressure Rocket Combustion

DESCRIPTION:

High chamber pressure rocket demonstrations of liquid oxygen-liquid hydrogen ignition and stable combustion at low oxygen/hydrogen mixture ratios of 0.1 to 1.2 were conducted on the IR&D Program in 1964. The tests conducted marked the first time low-mixture ratio combustors were successfully operated at high chamber pressures (3200-4200 psia) required for high pressure staged-combustion engines.

Since much of the IR&D work devoted to high pressure rocket engines had multiple objectives, it is not possible to isolate funds used exclusively for the high-pressure, low-mixture-ratio combustion work.

IR&D Brochure Identification: FP 64-82 (1965)
FP 65-121 (1966)

BENEFITS TO THE DOD RESULTING FROM THE EFFORT:

This work proved the feasibility of the staged combustion preburner concept and was one of the major elements paving the way for continued research and development on the high pressure oxygen-hydrogen rocket engine under Contracts AF04(611)-10372, AF04(611)-7435, and AF04(611)-11401.

TITLE: Advanced Cooling Technique for High-Pressure Rocket Engine

DESCRIPTION:

In 1962, a novel transpiration cooling method for very high pressure rocket engines was conceived. The original demonstration firings were conducted using company funds, but later the concept was extended and further developed on the IR&D Program.

Since no other cooling method has yet proved sufficiently efficient and durable at such high chamber pressures, our work has been the vital step in making high pressure rockets feasible. In recognition of this work, the inventor, John Chamberlain, was awarded the George Mead Gold Medal by United Aircraft Corporation in 1964.

Since much of the IR&D work devoted to high pressure rocket engines had multiple objectives, it is not possible to isolate the funds used exclusively for this cooling work.

IR&D Brochure Identification: FP 63-126 (1964)
 FP 64-82 (1965)
 FP 65-121 (1966)

BENEFITS TO THE DOD RESULTING FROM THE EFFORT:

When development is complete, the high pressure oxygen-hydrogen rocket made possible by this invention will provide the government with a significantly higher performance rocket propulsion system. This added performance makes a single-stage-to-orbit operations feasible, and greatly increases the attractiveness of recoverable rockets. Substitution of this high pressure rocket for conventional engines in multi-stage vehicles would generally increase payload by 10 to 40%.

TITLE: Boron-Reinforced Compressor Disc

DESCRIPTION:

A boron/resin reinforced titanium compressor disc has been designed, fabricated, and tested. This composite disc was tested in a rotating test rig to failure. A noncatastrophic type failure occurred at 110% of design speed. Initial test work is being performed on boron/aluminum composites for disc reinforcement also.

BENEFITS TO THE DOD RESULTING FROM THE EFFORT:

This work has resulted in a new disc design concept which could potentially save up to 40% of the total compressor disc weights. When coupled with composite blades, also in development, significant performance gains can be realized in a new generation of light-weight gas turbine engines.

TITLE: Controlled Vortex Turbine Performance Program

DESCRIPTION:

A major improvement in the turbine design capability has been provided under the controlled vortex turbine program which was initiated in 1964. Efficiencies have been improved greatly in the low velocity ratio range (Wheel Speed/Gas Velocity). This capability leads to improved design flexibility, particularly for high bypass ratio fan engines. The design system allows extension of bypass ratio to higher levels without resorting to gearing between the fan and the turbine.

BENEFITS TO THE DOD RESULTING FROM THE EFFORT:

This design system which uses a refined three-dimensional machine computation has shown turbine performance improvements in excess of 5% for the low velocity ratio range. The benefits ultimately will come in aircraft range improvement particularly for high bypass powerplants utilized in long-range missions. Lower accompanying wheel speeds also lead to lower weight for the powerplant. The controlled vortex design system is currently being used on all new engine programs and particularly on the advanced ATECG contract AF33(615)-15504.

TITLE: Advanced Main Burner Program

DESCRIPTION:

Work on the engine main burner has produced two easily identifiable changes in configuration. First to utilize the volume and length of the engine most efficiently, an annular configuration has been adopted and, secondly, the burner and compressor discharge diffuser have been consolidated. The net result is a major improvement in volumetric heat release for the total system. This work has led to a threefold increase in heat release rate and approximately 40% reduction in diffuser-burner length. Fundamental work on a water table analog, model mixing systems, and a two-dimensional annular burner rig section have provided essential design information.

BENEFITS TO THE DOD RESULTING FROM THE EFFORT:

Work on the advanced annular main burner led to its incorporation in new engine designs including the AMSA-ATEGG, Lift/Cruise, and the JT9D. A major improvement in thrust-to-weight ratio was provided for these engines, owing in part to the incorporation of this advanced annular main burner concept.

TITLE: Transonic Compressor Stage Program

DESCRIPTION:

A comprehensive single-stage transonic compressor program has been conducted since 1962 with the objective of increasing the flow per unit frontal area and the work per stage. The TS series of axial stages has demonstrated pressure ratio levels varying from 1.4 pressure ratio to approximately 2.3 pressure ratio per stage. Inlet stage pressure ratios on current production engines are in the 1.3 to 1.4 range. Advanced engines are now incorporating stages based on this experience at levels up to 2.3:1 pressure ratio. Fan efficiency on the order of 89% has been demonstrated.

BENEFITS TO THE DOD RESULTING FROM THE EFFORT:

Work on the transonic series of compressor stages has formed the basis for many of the most recent engine designs. This and other fundamental compressor work have enabled a reduction in the number of engine compressor stages. At the same time it has provided for an increase in overall engine pressure ratio with an accompanying cycle performance improvement. Under the major engine programs such as AMSA, Lift/Cruise, JT9D (Boeing 747), and JTF-17 (SST), the TS series of stages are the foundation for all new fan designs. In addition, such contracts as that on the turboaccelerator (AF33(615)-1305) have been utilizing compressor design information generated under the transonic compressor program.

EXAMPLES OF IR&D OF DIRECT BENEFIT TO DOD

Hamilton Standard
Division of United Aircraft Corporation

TITLE: Fiberglass-Shell, Steel-Spar Propeller Blade

DESCRIPTION:

Hamilton Standard has performed considerable research and advanced development on a composite propeller blade structure consisting of a load-carrying steel spar covered by a fiberglass shell. The latter acts both as the aerodynamic contour and as a protective sheath for the steel spar. This effort was begun in 1958 and has consisted of basic materials and structures evaluation, blade testing, and both engine and flight testing of complete propeller assemblies. The total effort since 1958 has been funded by approximately \$800,000 of IR&D and \$1,000,000 in government contracts. Over the last three years approximately \$500,000 of IR&D has been spent plus \$500,000 of government contracts.

BENEFITS TO THE DOD RESULTING FROM THE EFFORT:

The technology and experience from this program has now permitted application of this concept to military vehicles with substantial advantages over previous types of propeller blades. Compared to equivalent all-metal blades, an approximate 50% saving in propeller blade weight can be obtained. Typical installation advantages are as follows:

1. Application of the fiberglass-shell, steel-spar blade to the XC-142A aircraft represents an approximate 300% increase in payload weight as compared to equivalent all-metal blades. Similar savings are also being obtained on the X-22A aircraft.
2. This concept is being employed on the P2H aircraft on a spares replacement basis for the present hollow steel blades and will result in a 376-lb. weight saving per aircraft. A \$5,000 savings in hardware cost per aircraft will also result plus longer life and reduced maintenance costs.
3. Blades are now being developed for replacement of the dural blades on the P3C aircraft, which would result in a 800-lb. weight saving per aircraft.

Other benefits inherent in this blade concept are better compatibility with new radar signature reduction techniques, improved field repairability, and significant growth potential for incorporation of advanced materials such as titanium and new fiber composites for even further weight reduction. When combined with other recent Hamilton Standard propeller developments, such as the integral gearbox and variable camber concepts, this advanced blade structure represents a major breakthrough in the mission effectiveness of VTOL aircraft and subsonic transports.

**TITLE: Molecular Sieve Material for the Removal of CO₂ from
Closed Spacecraft Cabin Atmospheres**

DESCRIPTION:

The primary feature of a CO₂ removal system employing the molecular sieve material is its ability to be regenerated and reused for extended space missions. This Hamilton Standard IR&D project was initiated in 1959 and total IR&D funds have been approximately \$800,000. Half of this has been expended in the past three years. An additional \$300,000 of government-direct and -indirect contracts have been executed in hardware implementation of the molecular sieve system. Company efforts have encompassed over 5,000 hours of testing and have included consideration of three basic types of configurations:

1. Removal of CO₂ for dumping overboard.
2. Removal of CO₂ and H₂O for dumping overboard.
3. Removal of CO₂ and delivery to an accumulator for further processing.

The primary results of this effort have been to verify the acceptability of the molecular sieve approach and to determine the empirical data required for confident employment of this technique on manned spacecraft applications.

BENEFITS TO THE DOD RESULTING FROM THE EFFORT:

The results of the program have permitted the DOD to specify the molecular sieve concept for CO₂ removal in near future manned spacecraft missions at an equivalent weight savings of approximately 100 lbs. (for a 30-day, 2-man mission), as compared to current equipment in use. Correspondingly larger weight savings are obtainable with longer mission durations and/or larger crews.

EXAMPLES OF IR&D OF DIRECT BENEFIT TO DOD

Sikorsky Aircraft Division of United Aircraft Corporation

TITLE: IR&D-Sponsored Development of the Sikorsky S-64A (CH-54A) Flying Crane

Based on the previous records of utilizing military and commercial helicopters to transport external loads over terrain obstacles, it was recognized that a vehicle designed to accomplish this task more efficiently would be a requirement in the near future. Accordingly, Sikorsky Aircraft initiated design of the first prototype Flying Crane in 1958. This prototype was designated as the S-60 and utilized reciprocating engines. The S-60 was used for a number of years, improving the concept of a heavy lift, external load, VTOL aircraft. In order to obtain a more efficient vehicle for field operations, the S-64 turbine-powered Flying Crane was initiated in 1959. The total IR&D funds associated with both of the above efforts, excluding any engine development costs, amounted to over \$11,000,000. During the past three years this airframe and equipment development IR&D funding amounted to over \$1,000,000. Because of the above effort, it was possible to provide developed Flying Cranes for U. S. Army use when the need arose. The S-64 (YCH-54A) helicopters which were procured by the U. S. Army off-the-shelf and delivered to South Viet Nam confirmed the need for these heavy lift aircraft through the successful operations which showed the speed and ease with which bulky type cargos could be transported and its use as a battlefield recovery vehicle. Based on the number of downed aircraft which were recovered from inaccessible areas, it has been estimated that each S-64 Flying Crane has paid for itself four to six times over the initial cost of the vehicle.

BENEFITS TO THE DOD RESULTING FROM THE EFFORT:

In a comparison based on similar funded aircraft development programs, it is estimated that the development of the S-64 Flying Crane would have cost approximately thirty to forty million dollars. Through the above company-funded IR&D austerity program, this effort was accomplished for less than \$12 million, thereby providing the developed vehicle for about one-third of the normal costs. An appreciable time savings was also accomplished by this company-sponsored development in advance of the military requirement. This permitted the S-64 (YCH-54A) Flying Cranes to be delivered to the combat zone when needed in 1965. Had this program been initiated when the need arose for this aircraft in Viet Nam in 1965, it is estimated that a 3-year delay would have resulted in development of this aircraft toward fulfillment of the military's requirements.

The company-sponsored IR&D development of the S-64 Flying Crane led to achievement of the largest heavy lift helicopter in the free world. Many technical advances inherent in the development of this large-scale helicopter were achieved. The technology advancement achieved on the S-64 Flying Crane development allowed a more rapid transition to the current CH-53A assault helicopter presently in production. As a result of very successful operation, the equipment developed through the IR&D sponsored S-64 program has been ordered in large production quantities by the U.S. Army.

TITLE: Metal Blades and BIM (Blade-Inspection Method)

DESCRIPTION:

Starting in 1946, IR&D funds of \$6,000,000 were expended up to 1964 on metal rotor-blade development and associated efforts of aerodynamic configurations of blades. In the last three years, \$2,300,000 has been expended in further development, using latest blade structural and aerodynamic technology and application of titanium to provide even more reliable blades for military aircraft. This effort has been company funded and the significance to the government is earlier availability for military aircraft of blades which are durable (maintain performance characteristics under all service environments), structurally reliable, completely interchangeable (individual damaged blades replaced rather than entire sets), capable of maximum performance for minimum cost, and with potential to vary stiffness to any degree required by individual model configuration by use of proper material and weight distribution. Such IR&D effort normally runs 8 - 10 years before result of effort can be fully utilized in delivered aircraft.

In recent years these efforts have culminated in the utilization of an inspection system for blades known as BIM_R. This operates on the principle of pressurizing the internal cavity of the blade spar and installing an indicator at the root end which indicates any loss of structural integrity by showing loss of pressure when damage has penetrated through the structure. All tedious inspection requirements are eliminated and safety greatly increased because prior to each flight merely an observation of the indicator tells the pilot that the blades are satisfactory for flight. Thus the government, with metal blades, incorporating BIM, has been provided with aircraft that can be operated with the assurance that catastrophic accidents due to blade separation are highly improbable.

BENEFITS TO THE DOD RESULTING FROM THE EFFORT:

DOD has benefited from this effort by saving over \$1,500,000 per 100 aircraft per year on a Sikorsky model by elimination of frequent replacement of blades due to an arbitrary low replacement time that, for safety reasons, was used previously for blades without BIM. Since BIM permits "on condition" replacement, the ultimate benefits will be no replacement time other than as indicated by BIM. The Coast Guard currently procures and uses main rotor blades on this basis for the Sikorsky HH-52A helicopters.

Savings of \$800,000 per 100 aircraft per year result from elimination of repeated inspection of blades for damage which adversely affects structural integrity. There have been three incidents on S-58 aircraft in military use, three incidents on S-61 aircraft, and one on S-62 aircraft where BIM indicated

loss of structural integrity and the blades were removed prior to a catastrophic accident involving loss of life and equipment. The metal blade makes it possible to eliminate large inventories of blade spares through blade interchangeability rather than changing entire blade sets (as many as six blades in a set) and thus reduces warehouse space as well as procurement costs.

The metal blade with BIM incorporated provides DOD with a blade that retains its performance characteristics, remains serviceable under extremes of environmental conditions and, through the use of this inspection system, has a twenty-fold increase in blade reliability.

EXAMPLES OF IR&D OF DIRECT BENEFIT TO DOD

Norden
Division of United Aircraft Corporation

TITLE: Planar Distributed Function Generator

DESCRIPTION:

The Planar Distributed Function Generator is a totally new circuit element and possibly the first of a new family of circuits in which there is a relationship between its configuration and its performance so that a circuit can be designed from a specified transfer function. It is a type of monolithic nonlinear element made like an integrated circuit (see Aviation Week 17 January 1966). PDFG's would greatly simplify analog computers and can be used in place of nonlinear pots, cams, and other nonlinear elements.

Feasibility was proven and a computer program to design specific functions was developed on IR&D funds totaling about \$25,000. Work started in July 1963. Computing circuits using PDFG's are now being developed under contract AF33(615)-3938 for \$76,000, of which about \$27,000 has been spent.

BENEFITS TO THE DOD RESULTING FROM THE EFFORT:

It is too early to assign a specific dollar savings. When it is placed in use, large savings in cost, size and weight, with improved reliability and maintainability are possible. More rapid design can be achieved; higher frequency response and elimination of moving parts will be possible. A function generator now requiring 25 cubic inches and costing \$500 can be replaced by a unit in a can with a volume of less than 1/100 cubic inches, costing less than \$100. Applications include air data computers, weapon delivery, CRT displays, function shaping for amplifiers, etc.

TITLE: Development of the Glastrate Integrated Circuit

DESCRIPTION:

The present glastrate process was developed during 1965 and 1966 to allow for better isolation between components and to improve breakdown voltage characteristics of integrated circuit devices. In this process each active region of the device is separated from the other by a glass-like barrier.

Current development stresses improved techniques to establish near perfect isolation between all active components, reduce leakage currents, and increase frequency response by reduction of isolation capacitance. One very important factor is the elimination of PNP action experienced in normal epitaxial integrated circuits; thereby increasing the radiation resistance.

BENEFITS TO THE DOD RESULTING FROM THE EFFORT:

This process provides superior gamma radiation resistance characteristics. It is currently being used on the Minuteman and on the Poseidon programs. Increased radiation resistance is not measurable as a dollar benefit. However, an improvement of yields in dielectric circuits constructed by these techniques will, in production, reduce the cost of high reliability military electronics. Assuming a production cost reduction of one-third for the radiation resistance circuits made using this technology, a savings in excess of \$2,000,000 should be realized on the Poseidon program alone.

EXAMPLES OF IR&D OF DIRECT BENEFIT TO DOD

United Technology Center
Division of United Aircraft Corporation

TITLE: Electric Valve for Thrust Vector Control

During the first six months of 1966, United Technology Center expended approximately \$9,000 (20%/80% sharing plan) in IR&D funds to develop an electric valve to replace the hydraulic valve system for thrust vector control now in use on the Titan III-C, 120-inch-diameter Stage O booster. This work was performed on IR&D Project D-3, reported in the IR&D brochure dated November 1966.

BENEFITS TO THE DOD RESULTING FROM THE EFFORT:

This work has resulted in the development of a valve for use on the Titan III-C, Titan III-M, and Titan III-D programs, realizing large financial savings and higher reliability than on the current hydraulically actuated system. Specifically, replacement of the hydraulic valves and associated components with the electric valve and its associated components would save approximately \$33,000 per solid rocket motor. Based upon six launches per year, with two SRMs per launch, this represents a savings of \$396,000 per year. Most important, however, is reliability of an all-electrical system over the hydraulic system. Failure of TVC due to some hydraulic system malfunction would abort a \$12,000,000 to \$30,000,000 launch.

EXAMPLES OF IR&D OF DIRECT BENEFIT TO DOD

United Aircraft Research Laboratories

TITLE: Development of Boron Filament Production Processes

DESCRIPTION:

This program was initiated at the Research Laboratories in September 1963 as part of a broad research program to evaluate the potential of low density, high strength filaments for application to composite structures for aerospace use. Under the Corporate-sponsored program, approximately \$230,000 has been expended to date in developing the process of pyrolytic deposition of boron on a tungsten wire substrate. Other efforts, under Contract AF33(615)-2125, have been directed toward the development of unique processes for the formation of boron filaments, including direct melt methods. This government-sponsored effort has involved an expenditure of approximately \$500,000. To date neither the Research Laboratories nor any other contractor has been successful in forming boron filaments by the direct melt process.

BENEFITS TO THE DOD RESULTING FROM THE EFFORT:

Shortly after the initiation of effort by the Research Laboratories under the Corporate-sponsored program, we were successful in producing boron filament with tensile strengths on the order of 250,000 psi at a cost of approximately \$4500/pound. As a direct consequence of the Corporate-sponsored development effort (which is partially recovered under IR&D programs of the divisions), we have effected continued improvement in the quality of the filament with sharp decreases in cost. During the period from November 1965 to November 1966, we have increased the guaranteed tensile strength of production quantities from 250,000 psi to 450,000 psi and have reduced the price from \$1500/pound to \$331/pound in production quantities. Our latest quotation to the Air Force for the delivery of 2,000 pounds of filament was quoted at \$331/pound, and negotiations are currently in progress for the award of a contract to United Aircraft. This price, which is based on our true estimate of the cost and which includes a nominal profit, is considerably lower than that of any other producer in the United States and has provided a strong stimulus to the further exploitation of boron filament for use in aerospace products of interest to DOD. In fact, this low price already approaches the cost effective value quoted by one airframe manufacturer for material applicable to military airframe structures. Further reductions in price are already envisioned on the basis of the Research Laboratories continued process development activities.

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Reviewed Chief, RDD, WHS
IAW EO 13526, Section 3.5
Date: MAR 08 2011



AEROJET-GENERAL CORPORATION

9100 EAST FLAIR DRIVE EL MONTE, CALIFORNIA

BERNHARDT L. DORMAN
VICE PRESIDENT-FUTURE OPERATIONS

November 23, 1966

Mr. E. B. Harwood
Office of the Director of Defense
Research and Engineering
Room 3 D 1028
The Pentagon
Washington, D. C. 20301

Dear Mr. Harwood:

Mr. McKenzie has asked me to respond to Mr. Thomas L. Phillips' inquiry concerning the Defense Science Board's study of results from company IR&D activity.

As suggested in your letter, we have chosen only a few of the many significant IR&D programs. These examples are described below, with a brief explanation of the benefits resulting from this work and including cross-reference to our Special Report No. 3300 to DOD on Aerojet-General's IR&D program:

1. Lightweight Composite Armor (SM-21, Page I-19)

This work was conducted in FY's 1964, 1965 and 1966 and has resulted in an excellent protective personnel armor which is now being widely used in combat helicopters in Vietnam. This has included 4200 sets of installed crew armor for helicopters and 3200 sets of body armor. The IR&D work has been aimed at decreasing the weight, increasing the armor protective capability, and in reducing its cost.

2. Hyperthin Technology (LR-111, Page A-16)

This is the development of brazing together very thin photoetched platelets, to create metering grooves and openings for use in the manufacture of injectors and transpiration-cooled

interior walls of liquid propellant rocket combustion chambers. The same technology can also be used in making cooled turbine blades for gas turbines and turbojet engines. This technology has been used in the injector for a tactical missile motor design for the former Bureau of Naval Weapons and provides a marked advance in the capability of controlling flow in various types of rocket and air-breathing engine components. This project was initiated in 1965 and has saved time and manpower by providing a straightforward and positive method of fluid flow control in difficult portions of engine design.

3. Weapons Effects (CM-13, Page J-6)

Development of high-intensity, short-pulse generators of neutrons and X-rays in order to test by simulation of nuclear weapon effects the vulnerability of weapon systems components for DOD and its contractors. Work carried out in 1966 and being continued in 1967 includes the use of photo-sensitive explosives, explosive generation of high energy neutrons, and similar effects. The ability to conduct this work stems directly from plasma physics and explosive generator work carried out during the past several years under the IR&D program. The time-saving is great in that the company is able to undertake this complex work at once due to the experience and equipment now available through the IR&D effort.

4. Combustion Stability (LR-52, Page A-1)

Aerojet-General has developed a unique experimental tool, a "combustion-excitation chamber," which has proven to be extremely useful in explaining the basic causes of longitudinal combustion instability in liquid rocket engines and is helping significantly in the design of stable engines. The value of such capability to the DOD (and NASA) is great since it can help minimize costs and time delays of insuring stability in large rocket engines.

5. Acoustic Emissions in Stressed Metals and Fracture Mechanics (1964 and 1965 programs)

This work included development of a unique and valuable non-destructive testing technique for highly stressed metal structures such as large thrust chambers and propellant tankage. The technique employs an acoustic signature which has reliably

detected potential flaws and incipient failures in large, highly stressed metal structures. Examples are inspection of 260-in. solid propellant rocket cases and propellant tankage for Lunar Module vehicles. It is highly desirable for safety, cost, and schedule reasons to have this capability to detect incipient structural failures.

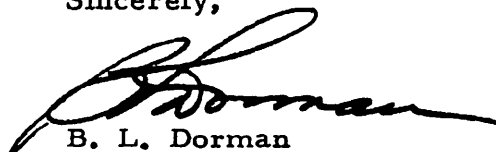
The code and page numbers indicated by the above programs refer to Aerojet-General's Report No. 3300 describing 1967 IR&D plans, as well as prior IR&D activity on continuing programs. The Summary volume for this report also includes facts on fifteen areas of IR&D resulting in significant accomplishments pertinent to our defense services and to your inquiry. In addition, Section IV of this Summary volume contains further facts and explanations of the relationships of Aerojet-General's IR&D activity to its services to DOD and other customers.
/This report contains proprietary information./

For several reasons, it would be difficult to provide meaningful quantitative data on dollars and hours saved DOD as a result of our IR&D. For one thing, IR&D is only one of the many indirect or overhead-type functions of our business, all of which combine to provide technical and other needed company capabilities. Direct benefits to DOD and other customers are normally represented in the products and the development services provided under contract. New concepts, as well as other technical capabilities generated under company IR&D are a most vital part of the company's efforts to maintain overall capabilities for current and future service to DOD and other customers.

With respect to your question regarding the "government portion" of total IR&D costs, all costs of our IR&D are treated as indirect costs of our business. The percentage of these costs which are reimbursable under cost type contracts has fallen from approximately 75% a few years ago to less than 50% at the present time. A schedule showing facts and trends in this regard is attached.

We hope the information we have provided will be helpful to the Defense Science Board in their inquiry into IR&D. Please let us know if additional information is desired.

Sincerely,



B. L. Dorman

Vice President - Future Operations

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Reviewed Chief, RDD, WHS
IAW EO 13526, Section 3.5
Date: MAR 08 2011



HERCULES INCORPORATED

RESEARCH DEPARTMENT • WILMINGTON, DELAWARE 19899 • TELEPHONE 302-656-9811

November 30, 1966

Director of Defense Research and Engineering
Attention: Mr. E. B. Harwood
Room 3D-1028
The Pentagon
Washington, D. C. 20301

Dear Sir:

In response to Mr. Thomas L. Phillips' letter of 4 November 1966, I am enclosing examples of significant benefits to the Department of Defense from our IR&D expenditures. I am supplying this data reluctantly, because I detect in the request for this data a continued misunderstanding of the true role of IR&D in industry. I would also like to answer some of the questions raised by Congress on IR&D.

In our competitive society, a nondefense industry's IR&D becomes a part of the cost of products sold by that industry. The amount of IR&D expenditures is carefully controlled by management to provide an optimum balance between current profit and future profit. IR&D is no different in defense industries. If expenditures are too low or improperly managed, the company will not have the technical competence to win new programs. If the IR&D expenditures are too high, the company will be noncompetitive in cost and again will not win new programs. This is particularly true with present DoD procurement practices which have a major emphasis away from cost plus fixed-fee-type contracts. The true measure of effectiveness of IR&D is whether the contractor is getting new business or indeed even staying in business. IR&D can, therefore, be exceedingly effective in fundamental technology without necessarily having any individual major breakthrough to point to as a shining example of the benefits to the government of IR&D.

Changes in defense contracting over the past five years have required the average contractor to do more IR&D. In our company, defense sales in 1961 were 99% CPFF. Most contracts were sufficiently broad to permit and even encourage a certain amount of R&D as part of the contract. In 1966, 12% of defense sales are CPFF, 38% are CPIF, and the remainder is some form of fixed-price contracts. Even the CPFF contracts are specific, well-defined, and devoid of any opportunity to deviate from prearranged program plans.

It has been our experience that the services are well aware of industry's IR&D work from review of brochures, from periodic reviews of programs, and from presentations by the contractors. At the same time, industry is well aware of the best way to utilize IR&D from information in service publications such as QDRI and SMEDO, from market research, and from service R&D RFP's. While the present system of IR&D allowance in defense industries leads to some duplication from company to company, this is not without benefit to DoD, since duplications of technology result in more competition and, in the end, a lower cost to DoD.

IR&D cannot be replaced by direct government funding of R&D for several reasons. Under present DoD practices, a substantial portion of R&D funds are siphoned off to support noncompetitive government laboratories with a relatively small amount left for industry. Direct R&D is often for specific work, minutely directed with little opportunity for change on the basis of accomplishments. While follow-on contracts often take into account new and promising leads, the exploratory process is slow and often stifling. Months and sometimes years elapse before promising leads can be supported by a contract. On the other hand, industry can rearrange its internal IR&D budget any time it is warranted by its own accomplishments or in response to changing DoD needs. In addition, company-sponsored IR&D is less costly to the government because the administration cost by the services is essentially nil. In contrast, a competitive procurement of R&D by one of the services for, say, \$100,000 must add to it direct cost of supervision, RFP preparation, and proposal evaluation. In addition, as many as a half dozen contractors

may spend up to \$10,000 each just in proposal preparation. Obviously, direct R&D support by the services is necessary and valuable despite the above, but it cannot supplant completely IR&D.

I hope that the preceding comments will be helpful to you in defending your present practices and in the formulation of new policies.

Sincerely yours,

R.W. Cairns

Director of Research

Enclosure

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Reviewed Chief, RDD, WHS
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Date: MAR 08 2011

EXAMPLES OF IR&D OF DIRECT BENEFIT
TO DEPARTMENT OF DEFENSE

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Reviewed Chief, RDD, WHS
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Cross-Linked Double-Base Propellants

Work on cross-linked double-base propellants described in the Chemical Propulsion portion of our IR&D brochure of 1964 and 1965 was initiated to improve specific impulse and the physical properties of double-base and composite-modified double-base propellants. The work resulted in propellants having the highest demonstrated specific impulse ever attained with solid propellants and with physical properties useable over a wide temperature range. Extensions of this work have been supported by the Air Force using exotic ingredients to obtain even higher specific impulse. While this research and development effort has not yet resulted in any specific end item, availability of these high specific impulse propellants will broaden potential accomplishments of the future.

Composite Propellants

Hercules initiated work as described in the Chemical Propulsion portion of our IR&D brochure of 1965 and 1966 on composite propellants. The research work has resulted in a family of propellants having excellent physical properties over a wide temperature range, greatly increased storability (particularly at high temperatures), which will undoubtedly result in a longer service life, and improved reproducibility as a result of clean chemical reactions. While these propellants have not been introduced into end items yet, it is anticipated that their future use will result in improved performance and longer life for weapon systems.

Nitrogen Oxide Studies

Hercules has maintained for many years a broad independent research program on "Raw Materials and Synthetic Chemicals." While research in this field is not limited to areas of direct interest to the DOD, developments of vital importance to the DOD have resulted and should continue to result from this work.

An outstanding example arises from studies of inorganic and organic nitrogen compounds which have been a continuing part of this program. During these studies, fundamental data were obtained on reaction equilibria and kinetics in systems involving the different oxidation states of the various nitrogen oxides. Based on this knowledge, it was subsequently possible to evolve a new process for the manufacture of nitrogen tetroxide (N_2O_4). This process has significant advantages over the older process, including freedom from by-products other than water and a product (N_2O_4) essentially free of chloride which tends to cause corrosion problems in storage and use.

In 1958, when the DOD asked for bids for supply of N_2O_4 , used as the oxidizer in the fuel system for Titan II and other subsequent missiles of the Titan class, Hercules was able to move speedily to establish commercial production based on the new process, and supplied its first N_2O_4 under DOD contract in 1959. Hercules is continuing to supply N_2O_4 to the DOD and is now the only large volume manufacturer of this important product.

The new process, stemming from Hercules IR&D work has brought benefit to the DOD by (1) providing an improved basis for needed additional national capacity for N_2O_4 manufacture, (2) contributing to a generally lower price structure for this chemical since 1959, and (3) furnishing a purer, less corrosive product of higher quality than previously available.

Finely Divided Polymers

Since well before World War II, Hercules has continued uninterrupted research on processes and materials related to coatings. Included in this program have been frequent studies of different approaches to the creation of polymers of extremely small particle sizes.

From this research on finely divided polymers have emerged processes for making stable suspensions of nitrocellulose, both in water and in organic solvents. These dispersions of fine particle size nitrocellulose have value to the DOD as described below. It should be emphasized that, from the same basic and continuing research program, additional benefits should be realized in the near future by the DOD as other polymers, in particular the polyolefins, become available in fine particle size. For example, coatings made from the finely divided polyolefins are very inert to chemical attack and resistant to solvents at most ambient temperatures. Inertness of these coatings in the presence of hydraulic fluids used in military aircraft has been demonstrated, and defense applications for prevention of corrosion can be anticipated.

Based on Hercules finely divided nitrocellulose, there are underway three developments of distinct value to the DOD.

1. A continuous system of slurry casting from inert diluent solid, double-base propellants (for missiles such as Talos and Terrier) can offer major advantages over batch methods in greater safety and lower cost. With previous forms of nitrocellulose, continuous operation has been impossible; with high density, fine particle size nitrocellulose it appears practicable. Following successful pilot plant demonstration runs with Hercules N-92 (dispersion of finely divided nitrocellulose in an inert diluent), the Naval Propellant Plant at Indian Head is proceeding to build a continuous process plant based on this type of nitrocellulose.

2. Igniter tubes for artillery shells of 175 mm. and other sizes are made from foamed polyurethane. This material has shortcomings in physical performance leading to misfires and is inert as regards energy contribution. Papers treated with aqueous dispersions of finely divided nitrocellulose provide igniter tubes of superior performance at lower cost than possible previously. This new form of nitrocellulose permits solvent-free lamination of tube components, a fabrication technique not otherwise possible. A high priority development program on igniter tubes based on Hercules finely divided nitrocellulose is now underway with the Army Ammunition Command at Picatinny Arsenal.

3. On artillery shells, the replacement of brass cartridge cases by combustible cases is desirable not only to conserve metal in short supply but also to allow simplified weapons design by eliminating need for extraction and disposal of the empty case. A combustible case has been developed based on cellulosic fibers impregnated with polyvinyl formal; it is expensive and the process for its manufacture is tedious. Use of finely divided nitrocellulose in hydrosol form as the impregnant appears very promising from both performance and cost viewpoints. Under Contract No. DA-28-017-AMC-3552(A) with Picatinny Arsenal, Armour Institute of Technology Research Institute is examining the nitrocellulose hydrosol approach. Hercules has submitted a proposal to develop the new system.

It is likely that there will emerge additional applications of benefit to the DOD based on finely divided nitrocellulose. For example, improvements are possible in the cotton cloth bags which carry incremental powder loadings. Impregnation of the cloth with hydrosols of finely divided nitrocellulose should improve humidity resistance and flammability characteristics of the bag. Picatinny Arsenal has expressed interest in exploring this possibility.

Polypropylene Filaments

Hercules independent research on polymer stability dates back to early work on cellulose-based polymers at a time well before World War II. With the advent of the synthetic polymer isotactic polypropylene in 1955, basic research efforts on polymer stability were intensified, and have been maintained with continuity to the present time.

Based on this fundamental research position, Hercules has led the industry in developing polypropylene of higher stability levels suitable for use in filaments, which because of their high surface-to-volume ratio represent the physical form of the polymer most susceptible to oxidative attack and extraction of stabilizers.

Because satisfactory stability to light and weathering has now been built into polypropylene, this polymer in monofilament and multifilament form has very immediate value to the DOD. For example, in sandbags used in Vietnam, polypropylene filaments provide many times the life of burlap or cotton fibers. Currently, the DOD requires 40,000,000 of these polypropylene filament bags; additional requirements totalling as many as 190,000,000 are anticipated.

Well-stabilized polypropylene filaments may soon provide additional value to the DOD in other applications. One example is Primacord; braided polypropylene multifilament is being developed as the outside cover for this device.

New Elastomeric Polymers

The Hercules program of continuing independent research on polymerization had its origins during World War II. Many different new polymers, copolymers and terpolymers have resulted, among them a number of synthetic elastomers. In the field of olefin polymerization, Hercules research has made major contributions toward the establishment as important elastomers of EPR and EPT, rubbery polymers based on ethylene and propylene (plus small amounts of a third monomer, for EPT types).

In the field of synthetic polyethers, Hercules research studies date back nearly to 1950 and are continuing at the present time. From these have emerged new elastomeric polymers and copolymers of epichlorohydrin.

Heat resistant materials having high strength at elevated temperatures are required by the Air Force for all types of advanced weapons systems. Ever increasing temperature resistance is needed in such subsystem components as tires, seals, hose, O-rings, and damping devices. For this purpose, because of their excellent resistance to heat, ozone and oxygen coupled with excellent mechanical properties and low cost, ethylene-propylene rubbers are under investigation in the Air Force Materials Laboratory (Non-metallic Materials Division; Elastomers and Coatings Branch) at Wright Patterson Air Force Base. From this same location, Request for Proposal No. F33615 67 R 1097 has recently issued listing EPR among the materials on which military specifications will be prepared under Air Force contract.

The same Request for Proposal lists epichlorohydrin rubber. This material has been shown to be superior to other elastomers as a long life O-ring compound for use in aircraft hydraulic systems; the work was done under Air Force Contract AF 33(615)-1668;

Project No. 7381 (Material Applications). Because of the combination of solvent resistance and oxidation resistance of this new rubber, additional applications of military value can be anticipated. For example, under U. S. Army Contract DA 44-009-AMC-1061(T), Douglas Aircraft Co. has reported to Fort Belvoir that this elastomer is among the most resistant to fuels.

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Date: MAR 08 2011

HAZELTINE CORPORATION

LITTLE NECK, N. Y. 11362

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Date: MAR 08 2011

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1966 December 9

XXX-66-M2256

Office of the Director of
Defense Research and Engineering
Room 3D-1028, Pentagon
Washington, D.C. 20301

Attention: Mr. E. B. Harwood

Gentlemen:

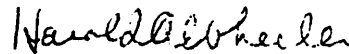
I received a request from Mr. Thomas L. Phillips several weeks ago to furnish information to the Defense Science Board in regard to a study they are making of the technical management aspects of company Independent Research and Development programs. Attached are four programs undertaken at Hazeltine within the past few years which, I believe, serve as good examples of projects which have developed into meaningful benefits to the Department of Defense. The projects selected are as follows:

- (1). Air-by-Air IFF System
- (2). Hand-Held IFF System
- (3). Microcircuit Module for IFF Transponder
- (4). ASW Near Field Measurement Array

All company expenditures mentioned in the examples are direct cost of material and labor.

I hope that this will be of use to the Committee in its study. If further discussion is desired on these or other projects, I would suggest you contact our Mr. J. W. Evans, Vice President.

Yours sincerely,



Harold A. Wheeler
Chairman of the Board

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EXAMPLE NO. 1

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TITLE: L-Band Air-by-Air IFF System.

BRIEF DESCRIPTION:

This program was started in the beginning of CY1963. In this program Hazeltine came up with a solution to a previously unsolved, important operational problem: Providing a practical, economical, and technically adequate IFF System for use by interceptor and fighter aircraft, to identify other aircraft.

As a result of a conceptual break through in the early months of the program, an all L-Band approach was devised. That is, it was concluded that it was feasible to integrate an L-Band IFF antenna with an X-Band AI radar antenna. In addition to specific antenna techniques, a total system design was formulated.

The total expenditure on this program, prior to receipt of the first Government contract, was about \$12,000. The effort included both Hazeltine and its wholly owned subsidiary, Wheeler Laboratories.

BENEFITS TO THE DOD RESULTING FROM THE EFFORT:

As a result of Hazeltine's initial feasibility findings, the Government awarded Hazeltine the first research/feasibility demonstration contract in 1964 FEB. An accelerated program for equipping an initial squadron of F-4B aircraft with the new system (nomenclatured AN/APX-76) began in 1965 JUL and resulted in the recent operational deployment to SEA of the first fighter squadron equipped with an automatic L-Band identification system. The approach has proven successful in extensive flight tests and has permitted the DOD to program the AN/APX-76 System into the services' fighter/interceptor aircraft, both for backfit and new production.

So far, the prime benefit to the Government has been the attainment of an initial operational capability in a time span not usually possible, namely less than three years from date of first research contract to date of first operational deployment.

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EXAMPLE NO. 2

DECLASSIFIED IN FULL
Authority: EO 13526
Chief, Records & Declass Div, WHS
Date: MAR 08 2011

TITLE: Hand-Held IFF for REDEYE Weapons System.

BRIEF DESCRIPTION:

This program was started in 1964 JUN. In this program Hazeltine devised an approach for a novel, hand-held aircraft identification set that could be used by REDEYE Weapons Teams.

Under this program, a breadboard unit was built and demonstrated to a group of DOD representatives. With the initial feasibility established, the DOD awarded Hazeltine contracts for development models.

The total expenditure on this program was about \$12,000.

The effort included both Hazeltine and its wholly owned subsidiary, Wheeler Laboratories.

BENEFITS TO THE DOD RESULTING FROM THE EFFORT:

As a result of Hazeltine's initial efforts and the ensuing development contracts, the DOD has been supplied with 10 models of the Hand-Held IFF Set; this set is currently undergoing operational evaluation by the Marine Corps.

Had it not been for Hazeltine's initial effort, it is possible that no feasible solution would exist at this time to the problem of providing a small IFF set to operate in conjunction with visually aimed weapons (where it is not possible to use a conventional IFF interrogator set).

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EXAMPLE NO. 3

TITLE: Microcircuit Module for AN/APX-46 IFF Transponder.

BRIEF DESCRIPTION:

In this program, started in the beginning of CY1963 and completed during CY1963, Hazeltine designed a portion of an IFF transponder in microcircuit form. The transponder was the AN/APX-46, used in a number of USAF and NATO aircraft. While this transponder was already a solid state design (except for the transmitter tube), it used only transistors and no integrated circuits. As an initial step in the conversion of IFF equipment to the then new integrated circuit technology, the coder-decoder circuits of the AN/APX-46 were designed using integrated circuits; a prototype module was developed successfully and tested. This work formed a basis for subsequent efforts, which have resulted in development of the AN/APX-64 and AN/APX-77 transponders, making maximum use of integrated circuits.

The total expenditure on this program was about \$24,000.

BENEFITS TO THE DOD RESULTING FROM THIS EFFORT:

Immediately following this effort, Hazeltine received a Navy contract for the design study of a microcircuit transponder. As a result of having already done some basic investigation and development, Hazeltine was able to make a greater contribution at lower cost to the Government under this contract.

Subsequent to the above study contract, the need arose to add a major set of new functions to the AN/APX-46, as part of the AIMS Program. Based on the background and experience gathered in the initial program, it was possible to incorporate all the new functions in the AN/APX-46 with no increase in overall size and weight, by making maximum use of integrated circuits. The new transponder, the AN/APX-64, is currently in production and being used in Navy and Air Force aircraft. Further, subsequent drops in production prices of integrated circuits resulted in a substantially lowered AN/APX-64 production price.

The overall benefit to the DOD from the initial program is the availability of a reliable microcircuit transponder with full AIMS capability at a significantly earlier time than would have been otherwise possible. The production price of this transponder is less than what the price of a functionally equivalent non-microcircuit unit would be. While it is difficult to estimate the resulting savings to the DOD, it is believed to be several million dollars.

EXAMPLE NO. 4

TITLE: Near Field Measurement Array

BRIEF DESCRIPTION:

This program was started and completed during CY1965. In this program Hazeltine devised and developed a means for determining the effective far field performance of a sonar or acoustic transducer array by making measurements in the near field.

It was determined that with an acoustic transducer test array having certain special properties, located in the near field, or immediate proximity of an operating array, the effective far field patterns of the operating array could be determined. Such a test array was built and installed for use at the Hazeltine water test site in Quincy, Massachusetts.

The total expenditure was about \$13,000.

BENEFITS RESULTING FROM THE EFFORT:

As a result of this effort, Hazeltine was able to render improved service on other concurrent DOD sonar programs.

During the course of this program, Hazeltine received a contract from the Navy for providing two types of near field arrays for the AN/AQS-10 helicopter carried, dunking sonar. These arrays are for the purpose of performance monitoring and measurement. One array is intended to be used with the AN/AQS-10 sonar on a permanently installed, performance monitoring basis, while the other is used for more precise measurement in a test tank. The work done under the in-house program provided the basis for, and to a large degree has made possible, Hazeltine's performance on the contractual program.

An additional potential benefit to the DOD is the possible application of these techniques for operational performance monitoring of larger sonars such as the AN/BQS-6, AN/SSQ-23, and AN/SSQ-26. Hazeltine is currently studying these applications.

It is not possible to estimate at this time the potential dollar savings to the DOD resulting from this program.



THE GARRETT CORPORATION

9851 - 9951 SEPULVEDA BOULEVARD • LOS ANGELES, CALIFORNIA 90009
TELEPHONE: SPRING 6-1010, ORCHARD 0-0131 • CABLE: GARRETTAIR LOS ANGELES

November 23, 1966

Office of the Director of Defense
Research and Engineering
Pentagon, Washington, D. C. 20301

Attention: Mr. E. B. Harwood
Room 3D-1028

Gentlemen:

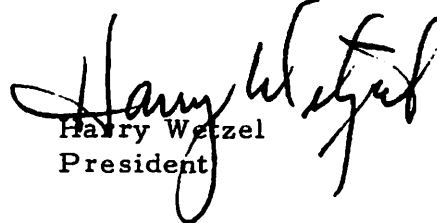
At the request of Thomas L. Phillips, I am enclosing six examples of The Garrett Corporation's IR&D effort that has resulted in significant benefits or payoffs to the Department of Defense.

We have conducted an intensive IR&D program for the past several years which has been geared to technological advances which will benefit the entire range of our products. Particular emphasis has been placed upon developments which not only increase the state of the art but yield longer life, more reliable and lower cost end products.

Please notify me if we can be of any further assistance.

Yours very truly,

THE GARRETT CORPORATION


Harry Wetzel
President

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Reviewed Chief, RDD, WHS
IAW EO 13526, Section 3.5
Date: MAR 08 2011

TITLE: JET FUEL STARTER TECHNOLOGY DEVELOPMENT

SUPPORTING DATA: This program was started in 1962 and was first identified in The Garrett Corporation's IR&D brochure for 1965 as Program Number 93-5-D1. Expenditures to date total approximately \$578,000.

DESCRIPTION: The objective of this program was to develop the technology necessary for gas turbine power unit which could be configured as a self-contained starter for main propulsion engines.

This objective has been fulfilled and the state of the art in small gas turbine engine technology has been advanced by the successful design, development, and demonstration of the feasibility of the Jet Fuel Starter concept. A 75-horsepower, lightweight, compact Jet Fuel Starter of the free-power-turbine configuration has been built and tested with company funds. To date, actual starting demonstration tests have been conducted on the Pratt and Whitney J57, JT8D, and TF 30 Engines and the General Electric CJ805 Engine.

BENEFITS: Application of the Jet Fuel Starter will provide military aircraft with a compact, self-sustained starting system that will eliminate the need for ground-support gas turbine APU's, solid propellant cartridges, or other externally supplied sources of starting energy. The cost per start with the Jet Fuel Starter system will be substantially lower than with any of the other "self-sufficient" systems now utilized, and life and reliability will be enhanced.

A new application for this technology is the Helicopter Emergency Lift Power Starting System (HELPS) which can apply to all types of helicopters. This concept can provide a power source for emergency starting of helicopters, auxiliary power while on the ground with the main engine shut down or, most important, a method of reducing the rate of descent and providing a significant improvement in autorotational safety in the event of main engine failure.

Other applications for which this small, compact engine could be configured include main propulsion in either pure jet or shaft power form, or as a power supply for electrical generator sets, hydraulic pumps, and compressors.

TITLE: ABRADABLE SHROUD DEVELOPMENT

SUPPORTING DATA: This program was initiated in 1966, and identified in The Garrett Corporation's IR&D brochure for 1966 as Program Number 93-7-D2. Expenditures to date on this phase total approximately \$52,000.

DESCRIPTION: The objective of this program has been to develop a suitable coating for compressor and turbine wheel shrouds that can be readily abraded by contact with the rotating wheels, without wheel damage, to minimize tip clearances and associated leakage losses.

To date, abradable shroud coatings compatible with gas temperatures up to 1700°F and suitable for abrasion by such diverse wheel and blade materials as Titanium 6Al4V and Inco-100 have been successfully demonstrated. Flame-spray application techniques have been developed to provide the coating with the essential bonding strength and resistance to thermal shock. A rub-tolerant coating has been demonstrated at 1800°F; successful demonstration of a fully abradable shroud coating compatible with gas temperatures in excess of 1800°F is expected to be accomplished before the end of 1966.

BENEFITS: The application of fully abradable coatings to axial-turbine shrouds has resulted in a significant improvement in overall turbine efficiency at maximum power with an associated increase in output power, and a decrease in SFC. Significant, although smaller improvements, are expected to result from the application of fully abradable coatings to centrifugal-compressor shrouds. Additional benefits are expected to be realized from simplified assembly procedures, relaxed build tolerances, and more efficient production laboratory testing with attendant savings in time and costs. The shroud-coating techniques are universally applicable to turbomachinery and will be used in the production of Jet Fuel Starters, Auxiliary Gas Turbine Power Units, and Turboprop engines. With the current trend toward higher power, higher pressure-ratio engines, leakage losses become more costly. The application of fully abradable shroud coatings will permit the potential of these engines to be more completely realized.

TITLE: CENTRIFUGAL COMPRESSOR DEVELOPMENT

SUPPORTING DATA: This program was initiated in 1966, and is identified in The Garrett Corporation's IR&D brochure for 1966 as Program Number 93-7-D2. Expenditures to date on this phase total approximately \$150,000.

DESCRIPTION: The objective of this program was to design and develop a high-performance, two-stage, centrifugal compressor with a wide range of surge-free operation for use in turboprop and other gas turbine products.

All design objectives have been met or exceeded. A unique compressor incorporating backward-curved blades has been developed with a demonstrated design-point efficiency in excess of 80 percent at a pressure ratio of 8.6:1. When applied to turboprop engines, surge-free operation is achieved at all transient and steady-state operating conditions without the need for variable geometry or interstage bleed provisions.

BENEFITS: The compressor aerodynamic performance demonstrated as a result of this development program represents a distinct advancement of the state of the art in engine design. A gain of over four percentage points in efficiency was achieved while affording a greater surge margin. This simple, fixed-geometry compressor is a significant milestone in the development of lightweight, high-performance engines. It is a major factor enabling the uprating of our T76 engine from 660 shaft horsepower to the 715 shaft horsepower. This uprated engine will be provided to the Navy. The flexibility of the design concept also permits a wide range of engine applicability. The same aerodynamic design, scaled to a single stage, is to be used in the 350 equivalent shp Auxiliary Gas Turbine Power Unit for the C5A Aircraft.

TITLE: DEVELOPMENT OF CORROSION-RESISTANT ALLOYS

SUPPORTING DATA: This program was initiated in 1963 and continued through 1965 under The Garrett Corporation IR&D Program identification 93-3-R2. Expenditures to date total approximately \$225,000.

DESCRIPTION: The objective of this program has been to determine the mechanism of hot-corrosion attack in gas turbines by the products of combustion of jet fuels and to develop new alloys that can withstand this attack even under severe salt-water ingestion.

The result is a series of cobalt-base superalloys, identified by the trade name "AiResist," which has been developed and tested both in the laboratory and on turbine engines. These alloys have shown almost no surface attack in highly corrosive (sulfur rich) atmospheres up to 2050°F that almost completely destroy other uncoated superalloys. Pilot lots (both cast and wrought) have been produced in several mills to verify uniform producibility.

BENEFITS: As the application of gas turbines in U. S. Navy surface crafts becomes more wide spread, new materials will be required to operate at temperatures and under conditions conducive to severe corrosion from sulfur and sea water. This new series of AiResearch-developed AiResist cobalt-base alloys actually resolve some of the major problem areas which are being encountered. These alloys can be regarded as the only available materials capable of surviving the corrosive conditions encountered in the stator and combustion-liner areas of "Marine" engines. Among the advantages of these alloys over any other existing material today are:

- (a) Marine gas turbine operation can be considered a reality.
- (b) Higher gas turbine operating temperatures can be accommodated.
- (c) Longer engine component life can be predicted owing to greatly decreased corrosion.
- (d) Lower operating costs can be predicted owing to less component replacements and the lower specific fuel consumption attendant with higher operating temperatures.

The use of these new AiResist alloys has been proposed to the U. S. Navy in a marinization program for the 500-hp Model 831 Gas Turbine Engine.

TITLE: TURBINE BLADE COOLING TECHNIQUE

SUPPORTING DATA: This program was started January 4, 1966, and was identified in The Garrett Corporation's IR&D brochure for 1966 as Program Number 93-5-D3. Expenditures to date on this program total approximately \$43,000.

DESCRIPTION: Significant effort was directed in five areas: Heat Transfer, Stress Analysis, Material Selection, Metal Joining, and Mechanical Design. The basic approach around which this work is concentrated is to either shroud the structural blade core with a cooling surface or to place a cooling surface internal to the blade structure.

BENEFITS: Through use of the feasibility study completed in 1965, two turbine blade conceptual designs were reduced to paper configuration. These are the (1) fin inside structure (SI) design and (2) fin outside structure (SO) design.

Design techniques applicable to sheet metal blade fabrication were developed including the following:

1. Casting, chem-milling, forming, and brazing of super alloys such as Hastelloy X, Waspaloy and Inco 625.
2. Six two-dimensional blades and one three-dimensional blade were manufactured.

Advantage to the Government is technology advancement in high temperature gas turbine engine design and operation. Cooled blades offer an economical solution to high-temperature engine operation problems.

TITLE: GAS BEARING RESEARCH

SUPPORTING DATA: General gas and process fluid bearing research has been underway at AiResearch since 1957. Expenditures from 1963 up to 1966 (to date) total \$203,000. 1965 and 1966 IR&D brochure identification is Program Number 93-17-1.

DESCRIPTION: There are significant advantages in using the process fluid itself for lubrication in turbomachinery because of limitations in the speed, life, and environmental capability of conventional bearings. We have made considerable progress and have built and tested many different configurations. These have been applied to working high speed machinery driven by turbines (including gas turbines) and electric motors. In addition, these bearings have been applied to generators, pumps, compressors and fans. We have solved the problems of stability and operation under a wide range of environmental conditions including temperatures from 3.6°K to 1000°K and different kinds of gases, vapors, and liquids. Major effort has been concentrated in conformable surface (foil) and pivoting pad types of bearings.

BENEFITS TO THE DOD RESULTING FROM THE EFFORT:

| <u>Program</u> | <u>Benefit</u> |
|--|---|
| Cryogenic Refrigerator for I/R Maser Coolers 77°K Nitrogen | Technical advancement in gas bearings on High Speed Turbomachinery results is long life bearings requiring no lubrication. |
| Cryogenic Maser Refrigerator 4.2°K Helium | |
| Cryogenic Parametric Amplifier Refrigerator - 3.6°K Helium | |
| Aircycle aircraft cooling turbine on gas bearings | Gas bearings promise improved service life, lighter weight, and no lubrication system. |
| Waste Heat Driven 5-Ton Refrigeration Unit | Turbocompressor using freon gas bearings permits use of pure freon - hence higher boiler temperatures. |
| Project SLAM - Turbocompressor Group | Turbocompressor for re-entry vehicles using gas bearings operates successfully at 1000° F air operating temperature. |
| Tire Inflation Turbocompressor | Gas bearings are suitable for high temper- ature, clean air pressure system. |

AVCO EVERETT RESEARCH LABORATORY

2385 REVERE BEACH PARKWAY • EVERETT, MASSACHUSETTS 02149

TELEPHONE: 617 389-3000

JAMES P. KENNEDY
MANAGER

November 30, 1966

Mr. E. B. Harwood
Office of the Director of Defense Research
and Engineering
The Pentagon
Room 3D-1028
Washington, D. C. 20301

Dear Mr. Harwood:

Subject: Request of Dr. Thomas L. Phillips of Dr. Arthur
Kantrowitz, Avco Everett Research Laboratory,
re IR&D Effort

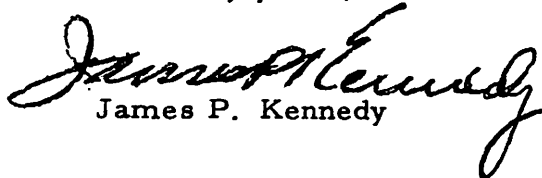
Although many examples exist of cases where research done under our Independent Research Program has been useful to Government programs, we submit three major examples which we feel are pertinent to the request.

The Independent Research brochure for this Laboratory is a part of the Avco Corporation Independent Research Program brochure for fiscal year 1966, dated October 1965, and prepared for the Department of Defense, Washington, D. C., and mailed to:

RTD (RTTR) Flash - Lt. Col. Martin
Bolling Air Force Base
Washington, D. C.

If there is any additional information required, we would be most happy to furnish same. I sincerely hope that the information submitted is timely and useful.

Sincerely yours,


James P. Kennedy

Enclosures

Page determined to be Unclassified
Reviewed Chief, RDD, WHS
IAW EO 13526, Section 3.5
Date: MAR 08 2011

TITLE: High Power Gas Laser Research

BRIEF DESCRIPTION:

When Started: 1962

Funding Level: \$268,000 (75% Government Support)

Significance of Effort:

The laser effort at Avco Everett Research Laboratory has concentrated on exploiting the fact that gases need not remain static. In electrically powered lasers, high speed flow can be used for the rapid removal of waste energy from the active laser region. In chemically powered laser systems, high speed flow is necessary for high power CW operation in that fuel must be replaced rapidly as it is burned. In flowing gas laser systems an additional degree of freedom is present in that waste heat can either be put into increase of thermal energy within the laser region or into flow energy, depending on the flow geometry. Thus, independent control of the gas temperature within the active laser region is made possible through flow. The use of flow with a laser system promises to produce a high power, chemically powered laser. Chemical lasers have important economic advantages since the cost of an electrical power source is eliminated, thereby producing significant savings to the DOD. In addition, the weight of the electrical power plant required for high power electrical lasers is eliminated which, for mobile applications, may be a crucial factor.

BENEFIT TO DOD:

This research, which has encompassed the cross-fertilization of laser technology with high power plasma physics, has resulted in four contracted programs with DOD agencies. They are:

| <u>Contract No.</u> | <u>Agency</u> | <u>Scope</u> |
|---------------------|--------------------------------|--|
| AF 33(615)-3832 | AF/RTD Avionics Laboratory | Research and development of high power lasers (Classified program) |
| AF 33(615)-3745 | AF/RTD Avionics Laboratory | Pulsed nitrogen laser development |
| N62269-3505 | Naval Air Development Center | Development of pulsed neon laser |
| AF 30(602)-4146 | AF Rome Air Development Center | Chemical Laser Research |

The above contracts will lead to important military applications which are of a classified nature.

TITLE: Investigation of MHD Generator Fluid Mechanics

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Reviewed Chief, RDD, WHS
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Date: MAR 08 2011

BRIEF DESCRIPTION:

When Started: 1961

Funding Level: 1.15 million (75% Government Support)

Significance of Effort:

This work has been concerned with research and development of MHD generators for high power output, limited duration, demand type electrical power supplies for ground, atmospheric, and space applications. An understanding of the fluid mechanics within the plasma bearing channel is vital for all of these applications. The research stated that MHD generators can be made to operate in an efficient and predictable manner. Studies are continuing on other aspects of MHD fluid mechanics, with particular emphasis on utilizing an unsteady flow for the production of alternating current. Success in this latter research will greatly enlarge the scope of application for MHD generators.

BENEFIT TO DOD:

This research has resulted in contracted programs with DOD agencies.

They are:

| <u>Contract No.</u> | <u>Agency</u> | <u>Scope</u> |
|---------------------|---------------|---------------------------------------|
| 1. AF33(615)-3225 | AF/ARPA | Combustion driven flt. MHD gen. study |
| 2. AF33(615)-3027 | AF/APL | Flight Vehicle MHD program |
| 3. AF33(615)-2846 | AF/APL | MHD generator impulse program |
| 4. AF40(600)-1116 | AF/AEDC | MHD generator burner system |
| 5. AF33(615)-1862 | ARPA/ASD | 20 MW MHD self excited generator |
| 6. AF40(600)-1077 | AF/AEDC | A&E Facility design services (LORHO) |
| 7. AF40(600)-1043 | AF/AEDC | R&D-MHD generator/accelerator(LORHO) |
| 8. AF33(657)-8380 | ARPA/ASD | 20 MW MHD rocket generator |

Under 8, 5 and 3 above, the practical utility of utilizing a chemical rocket engine to produce essentially unlimited amounts of electrical energy for limited durations has been conclusively demonstrated, and power levels up to 33,000 kilowatts have been achieved. Programs 4, 6 and 7 are concerned with the 20 megawatt LORHO Pilot Hypersonic Wind Tunnel of the USAF Arnold Engineering Development Center, and represent the first actual utilization of MHD power anywhere. USAF is presently considering construction of the full scale LORHO of several hundred megawatts' capacity, an application in which the utilization of an MHD generator power supply will result in savings of some \$16,000,000 to the Government. Programs 1 and 2 are concerned with flight (in atmosphere and exo-atmospheric) applications of limited duration high power level MHD Generators for weapon system applications, and have demonstrated the unique advantages of MHD in these applications.

TITLE: Investigation of Superconducting Materials, Coils and Devices

BRIEF DESCRIPTION:

When Started: 1961

Funding Level: \$323,000 (75% Government Support)

Significance of Effort:

I. Stabilized Superconductors

A significant fraction of the research effort has been devoted to understanding the behavior and investigating manufacturing techniques of stabilized superconductors.

A stabilized superconductor is one which allows superconducting coils of all sizes and shapes to be built with performance that is predictable in a true engineering fashion.

The idea for stabilized superconductors¹ was conceived and reduced to practice under Avco's MHD generator program for central station power plants, which is partly funded by independent research funds.

Further understanding of the principle and development of manufacturing techniques were generated in a continuing research program conducted with IR&D funding.

The existence of stabilized superconductors has played a very important technical, as well as economical, role in many government programs. It has not only made feasible the use of superconducting coils for flight or missile applications, but significantly reduced the cost of the superconductor itself.

The conductors used in the following coils being made for the Government were first developed under IR&D:

| <u>Contract No.</u> | <u>Agency</u> | <u>Scope</u> |
|---------------------|-----------------------------------|--|
| 1. NAS 5-10140 | NASA-Goddard Space Flt. Center | Superconducting magnet system for Apache Rocket |

The Laboratory is building a superconducting coil of 30 kilogauss which is to be launched in an Apache Rocket as part of an experiment in High Atmosphere Physics. The use of the stabilized Nb-Ti conductor is important due to the vibration and high g loading to which the coil is subjected. This application would be impossible without the use of a stabilized superconductor.

| | | |
|---------------|-------------------------------|---|
| 2. NAS 3-9684 | NASA-Lewis Research Center | Program to design, fabricate, and test four (4) fifty-kilogauss superconducting magnets |
|---------------|-------------------------------|---|

These are a set of four 20-inch internal diameter superconducting coils which will generate 50 kilogauss individually, and up to 88 kilogauss in combination. The use of the stabilized Nb-Ti conductor achieves both a decrease in cost and better performance.

| <u>Contract No.</u> | <u>Agency</u> | <u>Scope</u> |
|---------------------------|--|-------------------------------|
| 3. DA-01-021-AMC-12705(Z) | U.S. Army Missile Command, Redstone Arsenal, Alabama | High Energy repetitive pulser |

Up to the development of stabilized superconductors the use of superconducting coils for rapid charge and discharge was not possible. Under this program it was demonstrated experimentally that superconducting coils could be successfully charged and discharged at high repetition rates. This program is a continuing one, and up to now pulses of 60,000 joules delivered in milliseconds have been achieved.

| | | |
|--------------------|---|--|
| 4. AF 33(615)-3225 | ARPA - USAF Wright-Patterson AFB, Ohio | Liquid Fueled MHD Generator Feasibility Study |
|--------------------|---|--|

The use of a stabilized superconducting coil in this application makes the system feasible, while without it the system is not feasible.

II. Rotating Electrical Machinery

Another area where programs conducted under IR&D play a significant role is that of rotating electrical machinery. Specifically the effort has been based on generating the data necessary to allow superconducting rotating machinery to be designed.

The testing of an 8 KW alternator using a room temperature rotating armature and a stationary superconducting field coil was carried out under IR&D funding. The measured performance was published in the open literature.^{2,3}

The high current density and high magnetic fields to which a superconductor can be exposed make it a natural for use in lightweight compact electrical machinery. The use of this type of machinery points to the technical feasibility of lightweight electric propulsion which is being investigated for aircraft and ship propulsion in the two programs outlined below.

Up to now the testing program on the 8 KW generator offers the only available data on superconducting rotating power machinery.

Further work pertinent to rating machinery carried out under IR&D was the measurement of A.C. losses in superconductors.⁴ These measurements provided the basic data input required for analyzing superconducting machines with armatures made of superconducting material.

The published results, as well as direct transmittal of information generated under these programs to the U.S. Army and Navy, has resulted in an interest on the part of the Army and Navy in using superconductors to make lightweight electric machinery for electric propulsion systems, which have in the past been too bulky.

BENEFIT TO DOD:

Two current contracts which are a direct result of our IR&D programs are:

| <u>Contract No.</u> | <u>Agency</u> | <u>Scope</u> |
|----------------------|---|--|
| NObs-94528 | Naval Ships Systems Command | Study of electric ship propulsion machines using superconductor and cryogenic cooling techniques |
| DA-44-177-AMC-410(T) | U.S. Army Aviation Materiel Labs., Ft. Eustis, Va. | Superconducting electrical motor |

This program is aimed at using superconducting rotating machinery in the propulsion system of Army aircraft.

REFERENCES:

1. Kantrowitz, A. R. and Stekly, Z. J. J. "A New Principle for the Construction of Stabilized Superconducting Coils," Applied Physics Letters, Vol. 6, No. 3, February 1965.
2. Woodson, H. H., Stekly, Z. J. J., and Halas, E. "A Study of Alternators with S.C. Field Windings: I-Analysis," AERL AMP 197, February 1966. Presented at the IEEE Winter Power Meeting, New York, Jan. 30 - Feb. 4, 1966.
3. Stekly, Z. J. J., Woodson, H. H., Hatch, A. M., Hopple, L. L., and Halas, E. "A Study of Alternators with Superconducting Field Windings: II-Experiment," AERL AMP 198, February 1966. Presented at the IEEE Winter Power Meeting, New York, Jan. 30 - Feb. 4, 1966.
4. Di Salvo, F. "AC Losses in Type II Superconductors," AERL AMP 206, September 1966.

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Reviewed Chief, RDD, WHS
IAW EO 13526, Section 3.5
Date: MAR 08 2011

RADIO CORPORATION OF AMERICA
PRINCETON, N. J.



GEORGE H. BROWN
EXECUTIVE VICE PRESIDENT
RESEARCH AND ENGINEERING

December 13, 1966

Mr. E. B. Harwood
Office of the Director of Defense
Research and Engineering
Room 3D 1028
Pentagon
Washington, D. C. 20301

Dear Elliott:

In accordance with Mr. Thomas L. Phillips' letter of November 4 to me, I have asked our staff to prepare several outstanding examples of our effort for the past three years in independent research and development, which is supported in part by the Department of Defense.

Since our independent research and development is carried on in two distinct parts of the corporation, I am taking the liberty of submitting five items from the RCA Laboratories, the corporate research center here in Princeton, and nine items from the Applied Research activity of the Defense Electronics Products, the government division of the Radio Corporation of America.

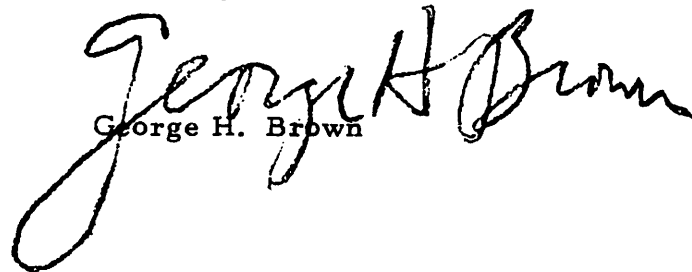
I should like to point out that the broad technical nature of our IR&D work, as well as the continuity of technical effort from year to year imply that specific benefits that accrue are generated by contributions from many IR&D projects. The specific IR&D projects referred to in the attached narratives are those which afforded the most significant contribution to the described benefits.

The dollar costs stated in these narrative examples were determined on the basis of allowable costs negotiated with the tri-service group in Washington. In other words, the government

portion of the total expense was allowed up to this percentage, but again was factored by the ratio of the total government business in the Radio Corporation of America to the total of our manufacturing business.

I hope this information is of value to you in your analysis of IR&D funds.

Sincerely,


George H. Brown

Enclosures

RCA LABORATORIES
IR&D OF DIRECT BENEFIT TO THE GOVERNMENT

TITLE: Solar Cells

BRIEF DESCRIPTION: Solar cells are used to convert energy in the form of sunlight directly into electrical energy. Research on these devices has been in progress at RCA Laboratories for over 10 years with support by both the Government and the IR&D program. The work has included the development of cells that will operate at higher temperatures and also cells that are resistant to high-energy radiation such as that encountered in space and in the vicinity of nuclear explosions. These most recent type of radiation-resistant cells uses a p-layer on a Li-doped n-layer. Research has been done also on thin-film low-cost, large-area solar converters culminating in a GaAs device that produces 135 watts/pound.

The work is described in the following RCA Laboratories IR&D Brochure* references:

1964 - pages 32-33
1965 - page 51
1966 - page 41

The corresponding IR&D expenditures related to the solar cell area are estimated as follows:

1964 - \$ 98,000
1965 - 126,000
1966 - 49,000

BENEFITS TO THE GOVERNMENT: Major contributions have been made to radiation-resistant solar cells. These now have a life at least 50 times that of previous cells. As a result the operating life of satellites, missiles and other space vehicles is no longer limited by solar cell failure in radiation fields. A major application of these cells is in space vehicles such as are being developed by the Navy-supported Applied Physics Laboratory at Silver Springs, Maryland. These cells have been used also in the Lunar Orbiter, the Relay communications satellite, and the Air Force communications satellite.

The thin-film solar converter research at RCA Laboratories has served to point the way to the potential future importance of such devices. Preliminary tests show a power output of 135 watts per pound as compared to 10 watts per pound for the present silicon cells. This is of significance for both space and ground applications.

* Copies of these IR&D Brochures are supplied to L. T. Muse, Contracting Officer, Headquarters, Naval Material Command, the agency responsible for negotiating IR&D funding for RCA Laboratories.

portion of the total expense was allowed up to this percentage, but again was factored by the ratio of the total government business in

TITLE: Magnetic Memories for Computers

BRIEF DESCRIPTION: Research on magnetic information storage techniques has been pursued at RCA Laboratories mainly as a part of the IR&D program since the early days of electronic digital computers. It continues at the present time as an important segment of our RCA-supported computer research, and has resulted in devices and systems presently being widely used in military equipment.

The most widely used form of digital storage in today's computers is the ferrite core memory. RCA Laboratories was among the first to synthesize and fabricate cores, and constructed the first operating memory system (with a capacity of 10^4 bits). A related element known as the transfluxer was conceived and first introduced by RCA. This device makes possible non-destructive read memories. Such memories are of extreme importance for military environment where security of the data is of the utmost concern.

In the research area of magnetic ferrites for memories, RCA has pioneered in the discovery of a number of new compositions of importance. These permit very high-speed switching and operation over a 100°C - temperature range.

Recent research relating to magnetic memories is described in the following RCA Laboratories IR&D Brochures*:

- 1964 - pages 22-23, 122-123
- 1965 - pages 25-27, 133-135
- 1966 - pages 22-23, 25-26, 143-145

BENEFITS TO THE GOVERNMENT: Specific research developments growing out of this research include a new square-loop lithium ferrite which makes it possible to operate a memory system over a 100°C - temperature range. The need for thermostating memories has been eliminated and the demanding thermal environment of missiles can be tolerated. The cycle time in memory operation can be more than halved. These are being used in the VIC computer for the Air Force. At present, RCA Laboratories is engaged in research on a manganese-cobalt ferrite which can operate at a very low power level and which is desired for use in space-borne memory systems where low power consumption is of the utmost importance.

A recent innovation of the RCA Laboratories is the monolithic ferrite memory system. This memory involves batch fabrication techniques and promises memories of extremely high bit densities, operating at low power levels, at intermediate speeds. This memory system combined with the manganese-cobalt ferrites is being developed for use in space-borne applications. The manganese-cobalt research and a small part of the monolithic memory work are now government-supported.

In a digital memory system, the use of active devices in the form of semiconductors or vacuum tubes has been necessary to operate the systems. This has posed a reliability problem in military environments that is quite severe. RCA pioneered the introduction of magnetic switches which reduce the required number of active devices. These magnetic switches can be used to operate either a memory or logic system and thus result in increased reliability. The principle of magnetic switches has also been utilized to construct fixed magnetic memories where the information is determined by wiring patterns in combination with magnetic elements. Such devices have found great application in air-borne military systems.

TITLE: MOS Transistor

BRIEF DESCRIPTION: Research on semiconductor materials and devices has been the largest segment of the RCA Laboratories IR&D program for at least the last six years. This category includes such devices as transistors, thyristors, tunnel diodes, switching diodes, varactor diodes, and integrated circuits. All of these are extensively used as replacements for vacuum tubes in military equipments of a great variety of types with substantially improved performance in most cases, with resultant increases in reliability, and with great savings in space, weight, and cost. The Metal-Oxide-Semiconductor (MOS) transistor has been chosen as a typical example of this research. RCA Laboratories has been a leader in MOS research, and the modern version of this device was invented there. This transistor was developed under the IR&D program and its theory, design, and construction were studied. The studies included silicon-silicon dioxide interface studies, and inversion layer formation which improved the stability of MOS devices. The stability and uniformity are being constantly improved and have now reached the point where they are satisfactory for most applications. Research on high-speed, low-power circuits was also carried out and methods for reducing parasitic capacitance and leakage were studied. Further details are given in the following RCA Laboratories IR&D Brochures*:

1964 - pages 43-44
1965 - pages 50-51
1966 - pages 35-37

The corresponding IR&D expenditures are estimated as follows:

1964 - \$440,000
1965 - 275,000
1966 - 415,000

BENEFITS TO THE GOVERNMENT: The MOS transistor provides major advantages in military communications and computer applications. Among these are important space and power savings. MOS devices require no additional components in digital circuitry with consequent higher packing density. In some uses (complementary symmetry pairs) they require only 1/5000th of the power of bipolar devices. They are being introduced in radar systems for the Air Force and are being developed for fuse applications by the Harry Diamond Laboratories of the Army. They are being used also in important classified applications. They are especially suitable for large computer arrays and here a read-out time of 10-15 nanoseconds is achievable. An MOS tetrode operating up to 500 mc is now being produced by RCA in sample quantities. This device is suitable for radar applications. MOS devices should eventually find use in many types of military equipment where their superior performance, simplicity and small size will prove of great value.

TITLE: Integrated Circuitry

BRIEF DESCRIPTION: Integrated circuitry has now pervaded our research to such an extent that it is no longer feasible to segregate it into a single research category. Instead, it plays a part in many individual items ranging from new materials through device research and into systems applications. New techniques have been developed such as vapor-phase growth, measurement of epitaxial layers, silicon-on-sapphire deposition, computer design of devices, and new methods of chemical and physical analysis. That part of the research program which has been segregated under the Integrated Electronics category is described in the following RCA Laboratories IR&D Brochures*:

1964 - pages 41-42
1965 - pages 46-48
1966 - pages 47-51

The corresponding IR&D funds expended are estimated as follows:

1964 - \$ 830,942
1965 - 877,925
1966 - 1,276,347

BENEFITS TO THE GOVERNMENT: Integrated circuitry is now being applied to such equipments as large-scale arrays in data processing, solid-state image sensors, computer memories, matrix-addressed displays, and microwave circuits. As an example of this research a project has been selected in the microwave area. Here an IR&D program is underway to produce an integrated solid-state transmit-receive module suitable for a variety of military systems, including a system for the protection of ASW ships against low-flying aircraft. The program was organized by RCA Laboratories and enjoys the support and participation of RCA's Systems Divisions. The program calls for over 300 man-months of effort the first year and a comparable effort the second year. It was launched in 1966 and is at present wholly RCA-supported. RCA Laboratories effort is at a 9-man level within the Laboratories (108 man-months for the year). In addition, the Laboratories supports an effort to develop an integrated tunnel-diode amplifier and to devise techniques for the integration of the power amplifier. This program is a major step towards the application of now well-established micro-electronic technology to the microwave part of the radio spectrum.

TITLE: Light Source for Military Surveillance

BRIEF DESCRIPTION: A new infra-red light source has been developed in the RCA Laboratories IR&D program using epitaxially-grown GaAs. This material is made by liquid-phase epitaxy, a process invented at RCA Laboratories. The source is based on the injection laser technique and generates high-intensity infra-red radiation. It has the capability to operate at room temperature. It is the first such device with a sufficiently high level of performance for practical applications. The work is a part of a broad basic research program on laser materials and devices supported by RCA Laboratories (see, for example, 1966 Brochure, Section on Quantum Electronics, p. 61-78). Further details are given in the following Brochures*:

1964 - pages 58-61
1965 - pages 69-73
1966 - pages 63-65

The corresponding IR&D expenditures are estimated as follows:

1964 - \$135,000
1965 - 343,962
1966 - 285,597

BENEFITS TO THE GOVERNMENT: The light source is suitable for night vision systems for use on tanks, trucks, planes, helicopters, etc. A greatly increased range is possible (the exact increase is classified). The life is about 20 times that of previous light sources and the cost is less by a factor of about two. Six units have been constructed by an RCA Product Division and delivered to Ft. Belvoir, (ERDL) for field test. A contract is under discussion. Light sources based on the same principle are suitable also for communication, displays, light-operated computers, and range finding. Some examples of these are given in the RCA item on Injection Laser Applications.

TITLE: Traveling Wave Masers

BRIEF DESCRIPTION: Applied research on masers began in 1959. The most recent work is described in the following sections of the IR&D brochures*prepared and submitted by Defense Electronic Products (DEP), an organizational unit of the Radio Corporation of America. The work was performed at the Applied Research activity of DEP.

Brochure references: 1961-B3, 1962-B4, 1963-B2, 1964-B3, 1965-B1. IR&D expenditures for projects described in above references: 1961-1965 \$243,500; Government portion \$188,500.

Early work on traveling wave masers using iron-doped rutile was extended in later years and in 1964, this material was shown to be applicable over the range 2-35 GHz. Meander line slow-wave structures were extended to x band operation and dual channel maser operation was demonstrated. The first known closed-cycle refrigeration maser system was successfully operated. The next significant technological advance was the achievement of 30 dB gain with 130 MHz bandwidth. This system used multi-coil stagger tuning with superconducting magnets.

BENEFITS TO THE GOVERNMENT FROM THE IR&D EFFORT:

The primary benefits result from the technological advances made during IR&D work that prompted various governmental agencies to award contracts to RCA for delivery of high performance maser systems. Such R&D contracts were awarded as early as 1962. Extending the dual-channel techniques to 3-channel and using broadbanding techniques with multi-coil superconducting magnets, a 3-channel maser was developed for the Navy (NOnr 4077 for \$202,000 - 1963) for application to monopulse radar. A tuning range of 5.4 to 5.9 GHz was achieved; a magnetic detuning technique, used for preventing saturation was originated in IR&D and is vital to pulsed radar applications.

The IR&D work described above resulted in sufficient advancements to contribute to the award of a contract to RCA to develop and deliver two advanced maser systems to Ft. Meade, one of which incorporated a closed-cycle refrigerator. These advancements included techniques to achieve extremely wide tuning ranges, closed-cycle operation using conduction cooling (no immersion in liquid helium) and reduction in pump power to well below 500 milliwatts, the heat-removal capacity of the refrigerator (Contract DA18-119-AMC-1026 for \$309,000). Other maser development contracts resulting in advanced equipment are:

DA18-119-sc 2428 \$143,000 1962
DA18-119-AMC 567 \$440,000 1963
NAS5 3397 \$46,000 1963
CST 7467 \$102,000 1964
NAS5-9745 \$235,000 1965
NOO173-67-6 0280 \$107,170 1966.

TITLE: Injection Laser Applications

BRIEF DESCRIPTION: Injection laser research was initiated in 1963, two years after RCA began its IR&D investigations of lasers in general. The injection laser work is described in the following sections of the IR&D brochures* prepared and submitted by Defense Electronic Products (DEP), an organizational unit of the Radio Corporation of America. The work was performed in the Applied Research Activity of DEP.

Brochure references: 1963-portion of B1, 1964-B1, 1965-B3. IR&D expenditures for projects described in above references: 1963-1965 \$234,200; Government portion \$185,500.

Practical injection lasers became available in 1963 that required cooling to 200°K for operation. In 1964, it was discovered that RCA-developed injection lasers could be operated in a pulse mode at room temperature. Special solid state electronic circuits that could supply 40 ampere pulses of duration 50 nanoseconds were developed so that these room temperature lasers could be utilized for communications. In 1965, the work was extended to include development of techniques to fabricate arrays of several lasers to obtain higher power output with consequent greater range capability. A room temperature laser communications system was demonstrated in the laboratory.

BENEFITS TO THE GOVERNMENT FROM THE IR&D EFFORT:

In addition to the general benefit of improving the state-of-the-art in the use of lasers, the primary benefit to the Government was the savings in time of delivery of equipment. In the 4-month period May-September 1965, three space-qualified laser transmitters were constructed for satellite-to-earth communication experiments. One of these units was flown on the Gemini GT-7 mission and performed as planned (although the system experiment was not completely successful). The background of IR&D work in injection lasers, laser arrays, and specialized solid-state circuits made the extremely short delivery cycle possible (Contract NAS9-4473 for \$105,500).

One other contract awarded to RCA required delivery of equipment on a short schedule also. Two laser intrusion alarm equipments with a 1-kilometer range day or night, with a self-check function and capable of 100 hours operation on D-size dry cells were delivered in 1966 to the Signal Corps within a five month schedule (Contract DA28-043-amc-02763 for \$25,000.)

RCA was also awarded a contract to deliver two subordinate units and one main unit of full-duplex transceivers, capable of voice communications over several miles. These units employed injection lasers in an array configuration devised during the previous IR&D investigations (Contract DA28-043-amc-1284E for \$109,000).

TITLE: Nuclear Radiation Research

BRIEF DESCRIPTION: This work is described in the following sections of the IR&D brochures* prepared and submitted by Defense Electronic Products (DEP), an organizational unit of the Radio Corporation of America. The work was performed at the Astro Electronics Division of DEP.

Brochure references: 1963-B5, 1964-B5, 1965-B4. IR&D expenditures for projects described in above references: 1963-1965 \$50,000; Government portion \$39,800.

Radiation testing of electronically active components was performed to explain previous observations of the unexpectedly severe effect of nuclear irradiation on oxide-passivated transistors, both bipolar and MOS. MOS transistors were selected for the first experiments based on the central role of the oxide in MOS transistor action and the potentially important use of large scale MOS arrays in spacecraft command and control systems.

Theoretical analysis of the test results established that electron and hole trapping in the oxide caused the observed change in electrical characteristics.

This determination provided the basis for a new annealing technique and special doping procedure to permit the fabrication of devices with greater radiation resistance. In addition, non-destructive testing procedures were devised to permit the preselection of more reliable transistors.

BENEFITS TO THE GOVERNMENT FROM THE EFFORT:

The benefits to date are primarily in the area of technology advancements. The use of irradiation-annealing techniques for preselection of reliable transistors is being considered for several satellite systems such as Global Com Sat and Advanced Tiros Operational Satellite. The work has been sufficiently fruitful that NASA awarded to RCA in early 1966 a technique development contract to investigate more fully the radiation effects in MOS devices (NAS5-10177 \$57,500). In addition such radiation-effects investigations are continuing in a portion of an Air Force contract - AF33 (615) c1140 \$100,000 - specifically concerned with "Radiation Hardening of Large Scale MOS Arrays." Both the Air Force's Ballistic Systems Division and the Research Technology Division have indicated concern about the influence of radiation on the choice of MOS transistors for their advanced computer hardware. However, techniques growing out of the original IR&D applied research which yielded partial solutions to the radiation problem in MOS devices should make practical the use of the MOS's in radiation hardened systems.

TITLE: Advanced Imaging Techniques

BRIEF DESCRIPTION: Research leading to the use of the isocon mode of operation in television camera tubes has been conducted under projects described in the following sections of the IR&D brochures¹ prepared and submitted by Defense Electronic Products (DEP) an organizational unit of the Radio Corporation of America. The work was performed at the Astro Electronics Division of DEP.

Brochure references: 1962-G7, 1963-portion of G6, 1964-portion of G5, 1965-G3. IR&D expenditures for projects described in above references: 1962-1965 \$109,900; Government portion \$87,200.

The initial IR&D research on improving television camera tubes for military and space applications requiring (a) low-light-level operation and/or (b) storage for slow-scan readout demonstrated that the electrical capacitance of the pickup tube storage target is a controlling factor in optimizing resolution and dynamic range. The isocon scanning mode was devised as an improvement over the conventional orthicon scan. Experimental evidence of a basic three-times reduction in noise was obtained. For "time-exposure" operation, an order of magnitude increase in viewing sensitivity is provided. The reduction in noise and consequent ability to detect smaller target voltage increments yield a higher dynamic range than is available by any other method of scanning television camera storage tubes.

BENEFITS TO THE GOVERNMENT FROM THE IR&D EFFORT:

The increased resolution, sensitivity and dynamic range resulting from these IR&D projects provide the Government with the means to achieve an extremely high performance television camera system for aircraft and space reconnaissance. As a result of this work, the Air Force has awarded a technique development contract to RCA for the continuance of the research work on the use of the isocon mode to achieve further extension of the dynamic range. This particular work - AF 33 (615) 5181 for \$53,000 begun in early 1966 - is aimed at eventually developing an advanced airborne image isocon transducer suitable for use with an image intensifier stage.

TITLE: Optically Pumped Lasers

BRIEF DESCRIPTION: Research on optically pumped lasers began in 1961 with investigations that year being performed in the Applied Research activity and the Aerospace Systems Division both of which are part of Defense Electronic Products. Descriptions of this work may be found in the following sections of the IR&D brochures* prepared and submitted by Defense Electronic Products, an organizational unit of the Radio Corporation of America.

Brochure references: 1961-C3 and portion of C2; 1962-C1, C2; 1963-portion of B1; 1964-portion of B1; 1965-B2.

IR&D expenditures for projects described in above references: 1961-1965 \$385,000; Government portion \$298,000.

The extremely high-power pulse characteristic of the optically pumped laser have been put to most extensive use in range finders. Techniques were developed that made practical the fabrication and integration of the many electrical and optical components into a unit capable of field use. Fabrication techniques involved solutions of many problems, two of which are those arising from rapid expansion of the laser rod caused by energy absorption and from electrode deterioration caused by the extremely high electrical current pulses.

BENEFITS TO THE GOVERNMENT FROM THE IR&D EFFORT:

The early IR&D work has resulted in the development of techniques to combine advanced electronic circuitry and optical subsystems with effective fabrication methods to produce, on a timely basis, range finders for field use. Other applied research related to generation of harmonic wavelengths of light have resulted in the awarding of technique development contracts to RCA such as those on blue-green and underwater lasers - NOBSr-87569 \$195,000 (1962); N62269-2617 \$26,000 (1964); N123-60530-51123a \$19,000 (1964); N173-32410(I) \$28,000 (1965).

Contracts awarded to RCA for the development of a variety of laser range finder equipment are:

| | | |
|--|-----------|--------|
| DA-36-039-sc-90894 | \$623,000 | (1962) |
| DA-28-043 AMC 00272(e) | \$269,000 | (1964) |
| N123(60530)-51212A | \$ 88,000 | (1964) |
| DA28 043 AMC 02075(e) | \$177,000 | (1966) |
| DA28 043 AMC 02904(e) | \$ 48,000 | (1966) |
| AF30 (602) 4261 | \$194,000 | (1966) |
| Subcontract from AC Electronics for the Army (FNP-51800) | \$762,000 | (1966) |
| Subcontract from Allison Division of GM for the Army (NEP-20031-LV) | \$100,000 | (1966) |

TITLE: FM Threshold Extension

BRIEF DESCRIPTION: Theoretical and experimental research on the application of phase-locked-loops to the detection of FM signals at low signal-to-noise ratios was conducted under projects described in the following sections of the IR&D brochures* prepared and submitted by Defense Electronic Products (DEP), an organizational unit of the Radio Corporation of America. This work was performed in the Communications Systems Division of DEP.

Brochure references: 1961-F4, 1962-F7, 1963-H6, 1964-H-11, 1965-portion of I-9.
IR&D expenditures for projects described in above references: 1961-1965 \$170,200;
Government portion \$133,200.

As part of a continuing project to improve military and space communications systems, means have been sought to avoid the penalties of FM communications links at low signal-to-noise ratios while maintaining their demonstrated and well-known superiority at high signal-to-noise ratios.

For military FM radio communications several alternative schemes have been evaluated both theoretically and experimentally to extend the low signal-to-noise ratio limit where (at the FM threshold) an abrupt and disastrous increase in receiver output noise occurs.

In pursuit of this end, phase-locked detectors were breadboarded to observe the second-order effects which dominate the realizable performance parameters and theory was evolved to account for practical limitations. A threshold improvement of 4.5 dB was demonstrated on an early system.

Subsequently, frequency modulation feedback (FMFB) was evaluated in detail and theory was developed for the combination of an extended range phase-locked detector with FMFB. A threshold extension of 8 dB was demonstrated making this technique applicable to highly portable military radio communications receivers.

BENEFITS TO THE GOVERNMENT RESULTING FROM THE EFFORT:

Because of applied research in technical areas associated with FM threshold extension, RCA was able to make an early decision to use a "phase-locked oscillator demodulator" instead of an FM feedback demodulator. Thus, months of study effort were eliminated in the work to deliver AN-TRC97 equipment (NOBSr 89545 \$7,999,000 starting in June 1963). The applied research listed above as well as that of "solid state frequency multiplication techniques" have contributed to a time savings in RCA getting into production on AN-TRC97A (NOBSr 93356 \$24,656,700 starting in October 1965).

Technological advancements made in the FMFB area contributed also to RCA's communications efforts on the deep space instrumentation facility for NASA's Lunar Orbiter-Subcontract P.O. 649600 from Boeing - starting in April, 1964.

TITLE: Cryogenic Thermoelectrics

BRIEF DESCRIPTION: Applied research on thermoelectric materials and devices began in 1960; however, the emphasis on cryogenic applications began in 1963. Work since that time is described in the following sections of the IR&D brochures* prepared and submitted by Defense Electronic Products (DEP) an organizational unit of the Radio Corporation of America. This work was performed in the Applied Research activity of DEP.

Brochure references: 1963-DL, 1964-DL, 1965-DL. IR&D expenditures for projects described in above references: 1963-1965 \$178,000; Government portion \$142,000.

Early research in this field led to the technological achievement in 1964 of fabricating a 6-stage thermoelectric module that attained a temperature of 159°K. As a result of refined analytical methods and improved fabrication techniques, a temperature of 135°K, the lowest figure at that time, was achieved in 1965. Observed performances were within 10 percent of theoretical predictions indicating accurate analysis and well-understood fabrication techniques.

BENEFITS TO THE GOVERNMENT FROM THE IR&D EFFORT:

In addition to the potential benefits of this advanced technology to the Government for application to solid-state devices that achieve extremely low temperatures, these IR&D efforts have been vital in at least three other specific areas of Government interest. One specific application is for photocathode refrigerators for image intensifiers in night vision equipment and for infrared detectors. In contracts with the military (Contracts DA44-009-amc - 477(T) and 1058 (T) for \$222,000 starting in 1964) equipments utilizing techniques first developed under IR&D have been carried from advanced development to military qualified devices. Typical of these is a refrigerator weighing 1.5 pounds, consuming 40 watts and providing refrigeration to -40°C.

A second application is temperature control of a pulsed laser cavity used in tank range finders. The IR&D work that was oriented toward miniaturization will prove absolutely essential to success in this area.

A third application is that of air conditioning in military vans and shelters. Reliability superior to that of mechanical refrigerators is the chief concern with size and noise reduction also important. Without the metallurgical techniques developed in early IR&D, it would not have been realistic to pursue at this time the high reliability needed for this application (Contract AF33 (615) 2755 for \$200,000 starting in 1965.) A technique development contract was also awarded to RCA in 1965 for research in attaining extremely low temperatures (AF33 (615) 2678 for \$154,000).

TITLE: High-Power Solid-State Transmitter Techniques

BRIEF DESCRIPTION: This work is described in the following sections of the IR&D brochures* of Defense Electronic Products (DEP) an organizational unit of the Radio Corporation of America. The work was performed by the Communications Systems Division of DEP.

Brochure References: 1964-F5, 1965-F3. IR&D expenditures for projects described in above references: 1964-1965 \$105,700; Government portion \$83,000.

The achievement of the high output power needed from transistor amplifiers for transmitters in the VHF and UHF bands requires the combined output of several high-performance transistors. The modern UHF transistor parallels several hundred transistors on a common silicon chip and obtains significantly higher power than is possible with a single large device. The significant work at RCA in this area provided early sample devices for the DEP research in high power, solid state transmitters for military requirements.

As a consequence of the paralleling of the basic devices, the input resistance of the resulting composite transistor is extremely low relative to the inductive reactance of the input. This characteristic, together with their sensitivity to over-voltage and over-current damage creates a very difficult requirement for maintaining a carefully controlled voltage standing-wave ratio over the operating band.

Techniques were devised on these projects which not only solved the drive and output combiner problems but also permit operation over the full military VHF and UHF frequency allocations without the requirement for tuning adjustment such as normally obtained by mechanical tuners or relays.

BENEFITS TO THE GOVERNMENT FROM THE IR&D EFFORT:

These techniques form the basis for the development of a 100-watt peak effective power linear amplifier under Air Force contract AF30 (602)-4373 for \$170,000, awarded to RCA in July 1966. This amplifier is to operate with high efficiency over the entire VHF band, 100 to 156 MHz.

This work also provided the basis for substantial improvements in the design approach for the VHF transmitters used in the Lunar Module (Grumman NAS9-1100) and the Command Module (North American NAS9-150) for the Apollo Program. The use of these techniques eliminated the need for the large number of variable capacitors, and consequent adjustment problems, used in the conventional approach to narrow band parallel operation. The combined value of those portions of both contracts concerned with the pertinent transmitters is approximately \$400,000.

TITLE: Efficient Multiple Frequency Antenna Feed Systems

BRIEF DESCRIPTION: This work is described in the following sections of the IR&D brochures* prepared and submitted by Defense Electronic Products (DEP) an organizational unit of the Radio Corporation of America. This work was performed at the Missile and Surface Radar Division of DEP.

Brochure references: 1963-G2, 1964-G2, 1965-H3. IR&D expenditures for projects described in above references: 1963-1965 \$145,000; Government portion \$187,100.

The improvement in efficiency and noise temperature for large Cassegrain antennas has been the result of a continuing research program making use of multiple waveguide-mode feed systems. The feed system efficiency has been increased over the past four years from about 70% to over 80% by reducing the spill-over energy which would fall beyond the useful antenna aperture and, at the same time, maintaining high aperture efficiency by even illumination. For radar systems operating at high elevation angles (the common operation for missile range instrumentation), this also results in a reduction in receiver noise due to the decrease in the effective temperature as seen by the feed horn. This unique multi-mode approach controls the aperture illumination function through the introduction of higher order waveguide modes with controlled amplitude and phase. Recent developments have further allowed simultaneous operation on frequencies separated by a factor of 2.5, providing operation of S and C bands on the same pedestal.

BENEFITS TO THE GOVERNMENT FROM THE IR&D EFFORT:

As this continuing program has progressed, it has provided advanced technical approaches for the development of antenna systems of the Apollo Ships Instrumentation Radar - (ASIR) NAS 5-9720 \$7,191,300 and the Apollo Acquisition Modification for the Capri Radar - NAS 5-10033 \$2,495,000. In addition, the technical leadership provided by these IR&D projects has been recognized through the award of advanced technology studies for the Applied Physics Laboratory (Feedhorn Study for Tartar D Radar System - APL 271-707 - \$108,000.) and NASA (Array for Meteorological Satellite - NAS 12-149 - \$50,000.).